

# THE CARTOON INTRODUCTION TO CLIMATE CHANGE

BY GRADY KLEIN AND  
YORAM BAUMAN, Ph.D.  
THE WORLD'S FIRST AND ONLY STAND-UP ECONOMIST

THE **CARTOON**  
INTRODUCTION TO  
**CLIMATE**  
**CHANGE**



WE'RE GRATEFUL TO THE FOLLOWING PEOPLE AND ORGANIZATIONS FOR HELPING TO MAKE THIS BOOK POSSIBLE, INCLUDING VIA GENEROUS CONTRIBUTIONS ON **KICKSTARTER**.

JAMES ADCOCK  
BRIAN ARBOGAST  
MARCIA BAKER  
REBECCA TUTTLE BALDWIN  
(SEE CAMEO OF MARK, PAGE 194)  
THE BAUMAN FAMILY  
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(SEE PAGE 142)  
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(SEE PAGE 98)  
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LARS HENRIKSON  
THE HILDEBRAND FARM FAMILY  
(IN MEMORY OF ALEX AND BARBARA)  
(SEE PAGE 176)  
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(SEE CHIPPER, PAGE 144)  
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(SEE KIRAN, PAGE 193)  
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# THE **CARTOON** INTRODUCTION TO **CLIMATE CHANGE**



BY **GRADY KLEIN** AND  
**YORAM BAUMAN, Ph.D.**  
THE WORLD'S FIRST AND ONLY **STAND-UP ECONOMIST**

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ISLAND PRESS, 2000 M STREET NW, SUITE 650, WASHINGTON, DC, 20036

ISLAND PRESS IS A TRADEMARK OF ISLAND PRESS/CENTER FOR RESOURCE ECONOMICS.

LIBRARY OF CONGRESS CONTROL NUMBER: 2014938166

PRINTED ON RECYCLED, ACID-FREE PAPER ♻️

MANUFACTURED IN THE UNITED STATES OF AMERICA  
10 9 8 7 6 5 4 3 2 1

**KEYWORDS:** GLOBAL WARMING, GREENHOUSE GASES, FOSSIL FUELS, ENERGY  
EFFICIENCY, ECONOMIC DEVELOPMENT, CARBON DIOXIDE, ICE-AGE, MILANKOVITCH  
CYCLES, CAP-AND-TRADE, CARBON TAX

*FOR ANNE AND LIAM AND BENJAMIN  
—GK*

*FOR MY FRIENDS AND MENTORS AT REED COLLEGE AND SIGHTLINE INSTITUTE,  
ESPECIALLY NOEL NETUSIL, MIKE FOLEY, AND ALAN DURNING  
—YB*



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**PART  
ONE**  
*OBSERVATIONS*





# CHAPTER 1

## INTRODUCTION

**TWO STORIES ARE  
GOING TO DOMINATE  
THE 21ST CENTURY.**



**STORY #1 IS ABOUT ECONOMIC GROWTH, ESPECIALLY IN POOR COUNTRIES IN ASIA AND AFRICA.**



**CAPITALISM AND FREE-MARKET ECONOMICS ARE GOING TO CREATE A LOT OF NEW WEALTH...**

YOU'RE FEELING THE BENEFITS OF WHAT ADAM SMITH CALLED THE **INVISIBLE HAND.**



YOU CAN LEARN MORE ABOUT THAT IN THE **CARTOON INTRODUCTION TO ECONOMICS.**



**...AND GIVE MANY MORE PEOPLE THE OPPORTUNITY TO PURSUE THEIR DREAMS.**

I WANT TO BE A **DANCER!**

I WANT TO BE AN **ASTRONAUT!**



AS FAMILIES GET WEALTHIER, THEY TEND TO HAVE **FEWER CHILDREN...**

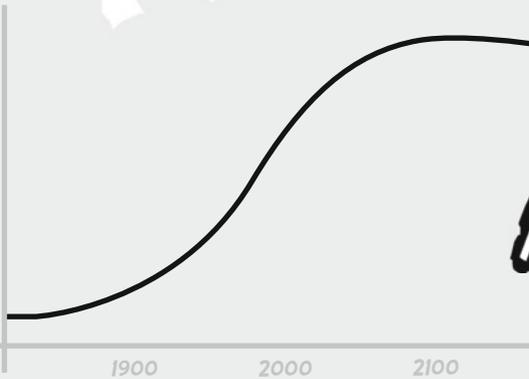


HAVING MORE KIDS IS **NOT** ONE OF MY DREAMS!

I WONDER **WHY?**



... SO THE WORLD POPULATION IS LIKELY TO **PEAK** AT ABOUT **10 BILLION** PEOPLE AND THEN SLOWLY DECLINE.



**ENOUGH ALREADY!**

AS A RESULT, **STORY #1** POINTS IN A DIRECTION THAT'S NOTHING SHORT OF **MIRACULOUS**.

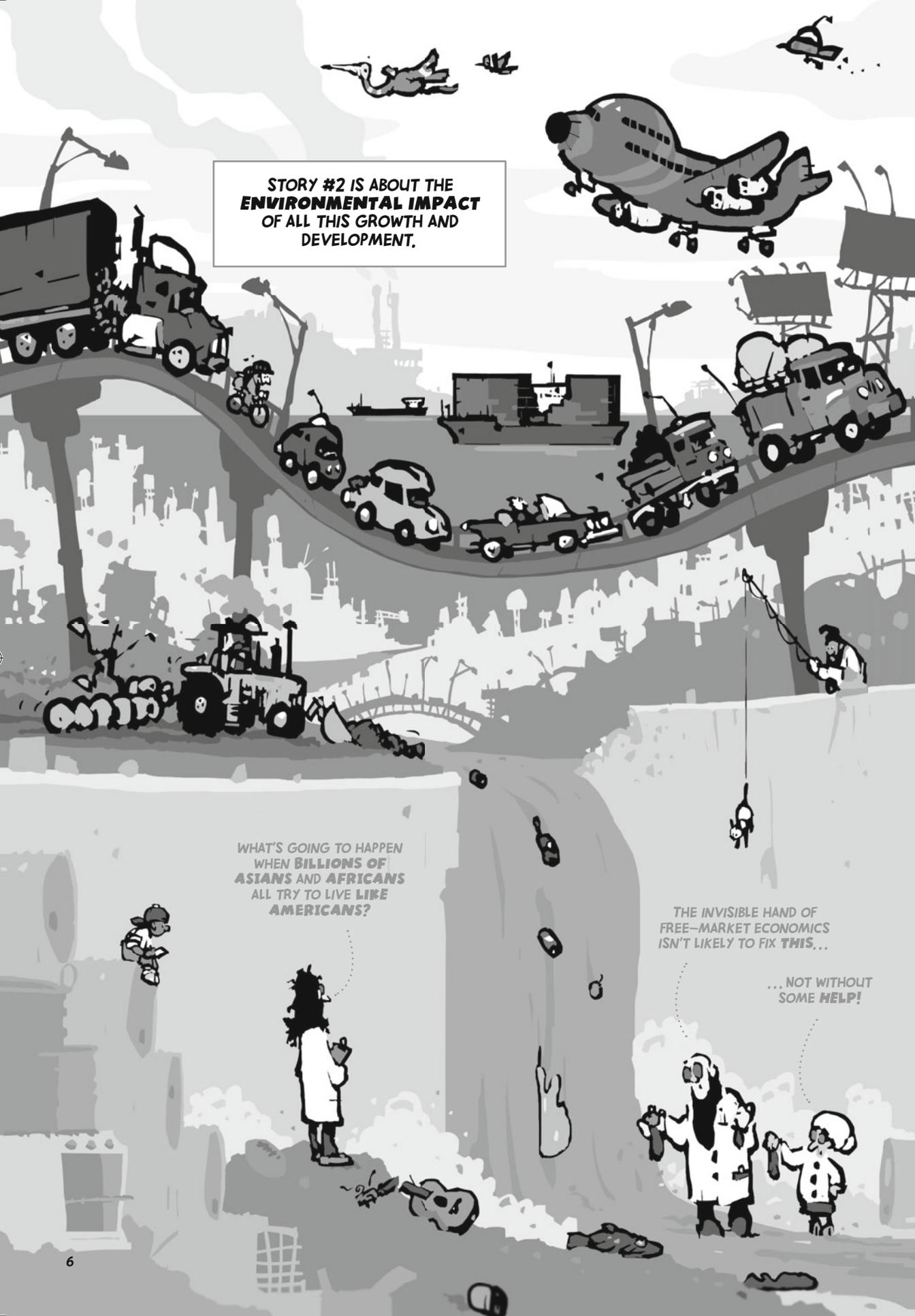


A WORLD OF **2-6 BILLION WELL-EDUCATED** AND THEREFORE **HEALTHY** AND **WEALTHY** PEOPLE!

IT SEEMS **TOO GOOD TO BE TRUE!**



BUT WHAT ABOUT **STORY #2?**



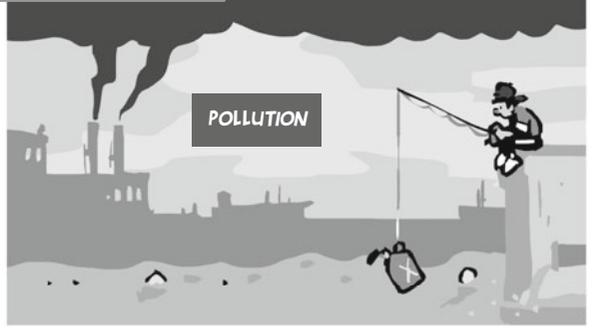
**STORY #2 IS ABOUT THE ENVIRONMENTAL IMPACT OF ALL THIS GROWTH AND DEVELOPMENT.**

WHAT'S GOING TO HAPPEN WHEN **BILLIONS OF ASIANS AND AFRICANS** ALL TRY TO LIVE LIKE **AMERICANS?**

THE INVISIBLE HAND OF **FREE-MARKET ECONOMICS** ISN'T LIKELY TO FIX **THIS...**

... NOT WITHOUT **SOME HELP!**

**ENVIRONMENTAL CONCERNS COVER ALL SORTS OF TOPICS.**



**THIS BOOK FOCUSES ON CLIMATE CHANGE.**



CLIMATE CHANGE IS A **POLITICALLY CHARGED ISSUE...**

YOU'RE A **DENIER!**

YOU'RE AN **ALARMIST!**



... BUT IT MIGHT BE POSSIBLE TO FIND SOME **COMMON GROUND...**

THAT COMMON GROUND BETTER BE 6 FEET UNDER BECAUSE **WE'RE ALL GOING TO DIE!**

NONSENSE, **WE'RE ALL GOING TO LIVE!**



... **BY THINKING OF CLIMATE CHANGE AS A THREAT.**

List of Threats:

Violent Video Games

National Debt

Terrorism

Asteroids

Bird Flu

Stupidity

Junk Food

Polluted

Drinking Water

Bad Spelling

poverty

Space Aliens

Reality TV

HOW DOES **THIS ONE** COMPARE?



MAYBE IT'S AN **EXISTENTIAL THREAT**...

... AND MAYBE IT'S ONLY A **MINOR THREAT**...

CLIMATE CHANGE COULD  
TURN THE EARTH INTO AN  
**ALIEN PLANET.**

HOW DO YOU KNOW IT  
WON'T BE AN **AWESOME**  
ALIEN PLANET?

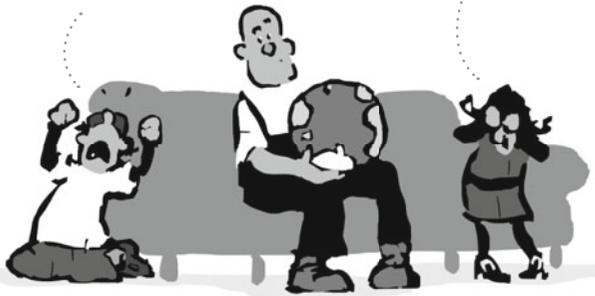


... AND MAYBE IT'LL BE **DECADES** BEFORE WE KNOW FOR SURE.

AND BY THEN IT MIGHT  
BE **TOO LATE TO**  
**DO MORE!**

OR TO DO  
**LESS!**

NO WONDER  
CLIMATE CHANGE IS  
SUCH A **WICKED**  
**PROBLEM.**



THIS BOOK WILL HELP YOU **MAKE UP YOUR OWN MIND.**

AND LEARN **WHAT**  
**YOU CAN DO**  
**ABOUT IT...**

... AND WHAT  
WE CAN **ALL DO**  
**TOGETHER!**



YOU MIGHT FIND IT HARD TO BELIEVE THAT HUMANS CAN  
INFLUENCE THE ENTIRE PLANET...



... BUT THERE'S LOTS OF SCIENTIFIC EVIDENCE THAT  
HUMAN ACTIVITY IS CHANGING THE CLIMATE.

MOSTLY AS A RESULT OF  
BURNING FOSSIL FUELS AND  
DEFORESTATION.

AND SOMETIMES BOTH  
AT THE SAME TIME!

1950s



2000s



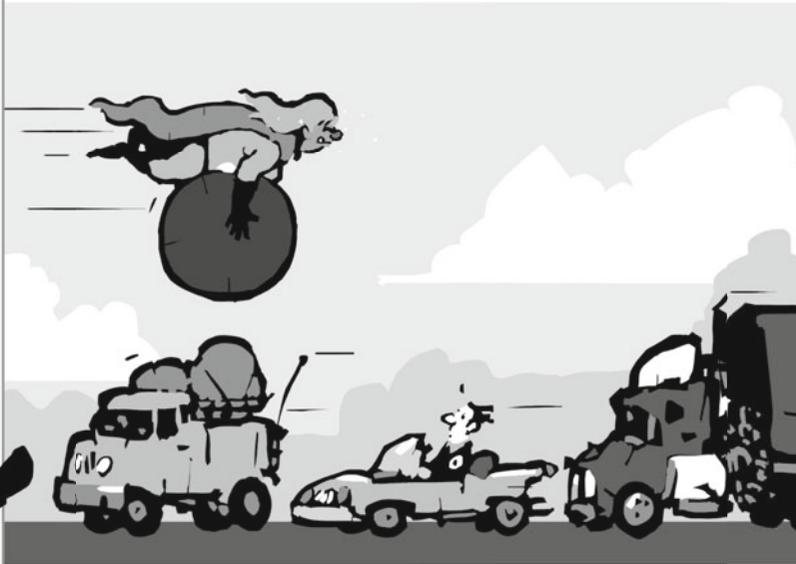
THIS BOOK IS ABOUT THE **SCIENCE**  
OF CLIMATE CHANGE...



...AND HOW CLIMATE CHANGE MIGHT  
AFFECT **LIFE ON EARTH**...



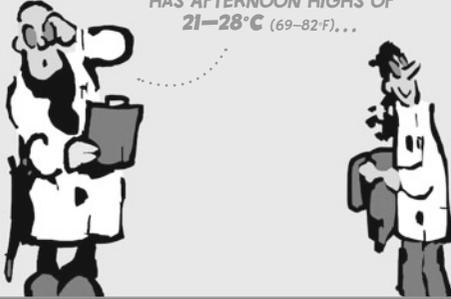
...AND **WHAT WE CAN**  
**DO ABOUT IT.**



A GOOD PLACE TO START IS WITH A FEW **DEFINITIONS...**

**CLIMATE** REFERS TO WHAT THE WEATHER IN A CERTAIN PLACE IS **USUALLY** LIKE.

SEATTLE IN JULY **USUALLY** HAS AFTERNOON HIGHS OF 21–28°C (69–82°F),...



**USUALLY** DOESN'T MEAN **ALWAYS**...

... AND IT **ALMOST NEVER** RAINS!

SOUNDS **PERFECT** FOR A WEDDING!



... SO YOU SHOULD THINK OF CLIMATE AS **AVERAGE WEATHER**...

**SORRY!** THIS IS VERY **UNUSUAL**.



CLIMATE IS LIKE YOUR **PERSONALITY**.



WEATHER IS LIKE YOUR **MOOD**.



... AND **CLIMATE CHANGE** AS A **CHANGE IN AVERAGE WEATHER**.

ON AVERAGE, THESE FLOWERS NOW BLOOM **ONE WEEK EARLIER** THAN THEY DID 30 YEARS AGO.



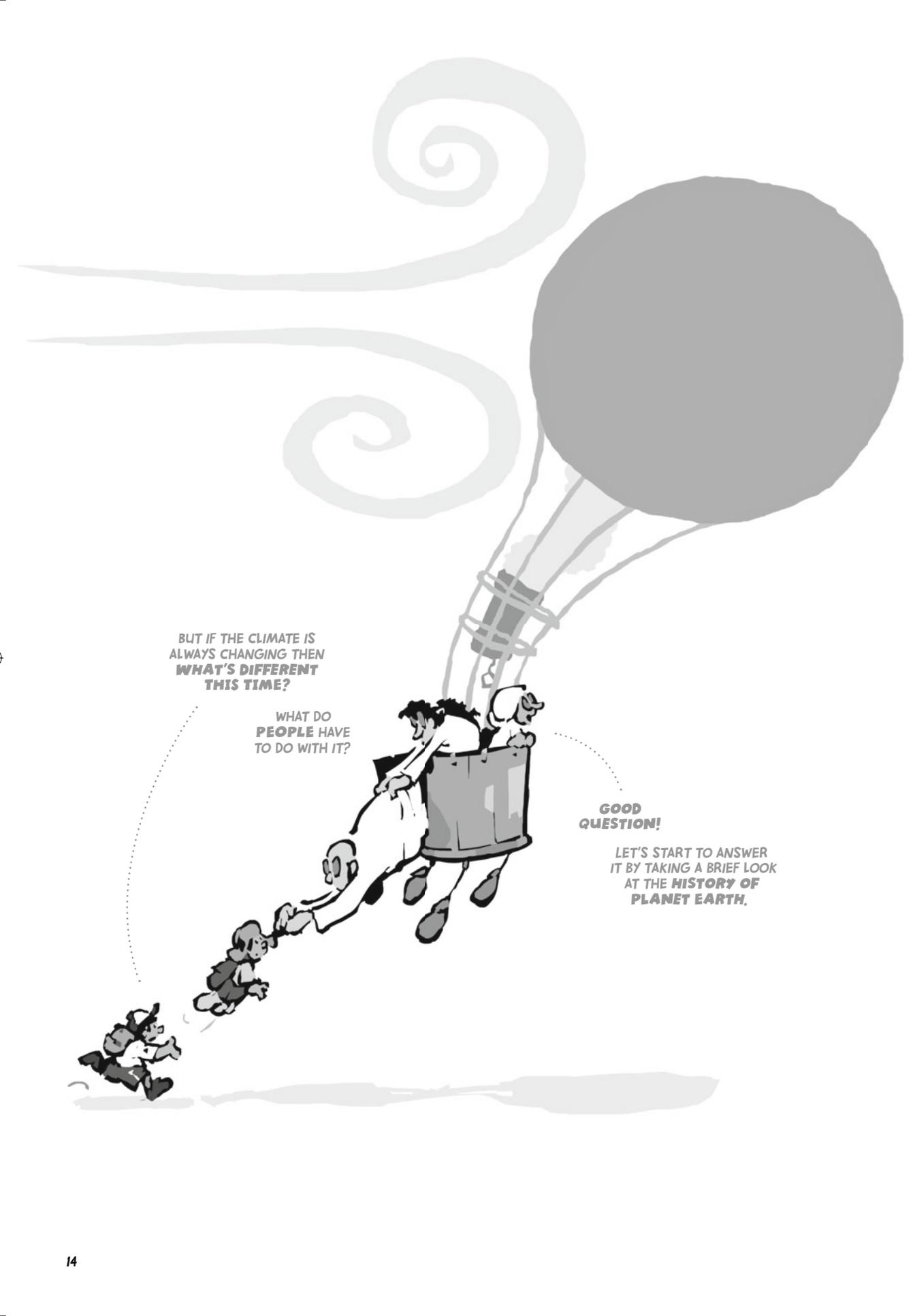
...AND WITH AN **OBSERVATION.**

EARTH'S CLIMATE  
HAS **ALWAYS**  
BEEN IN FLUX.

HERE ON PLANET EARTH,  
CLIMATE CHANGE  
HAS **ALWAYS BEEN**  
A FACT OF LIFE...

... AND IT  
**ALWAYS**  
WILL BE.





**BUT IF THE CLIMATE IS  
ALWAYS CHANGING THEN  
WHAT'S DIFFERENT  
THIS TIME?**

**WHAT DO  
PEOPLE HAVE  
TO DO WITH IT?**

**GOOD  
QUESTION!**

**LET'S START TO ANSWER  
IT BY TAKING A BRIEF LOOK  
AT THE *HISTORY OF*  
PLANET EARTH.**

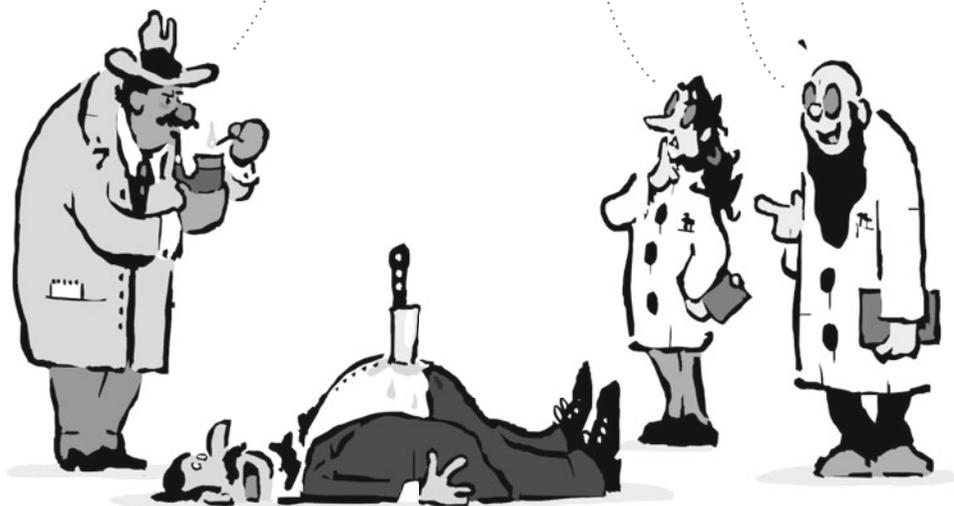
# CHAPTER 2

## A BRIEF HISTORY OF PLANET EARTH

TELL ME  
**EVERYTHING**  
THAT'S HAPPENED  
SO FAR.

WELL, FIRST  
THE **EARTH**  
COOLED...

... AND  
THEN THE  
**DINOSAURS**  
CAME...



THE EARTH FORMED ABOUT  
**4.6 BILLION YEARS AGO.**

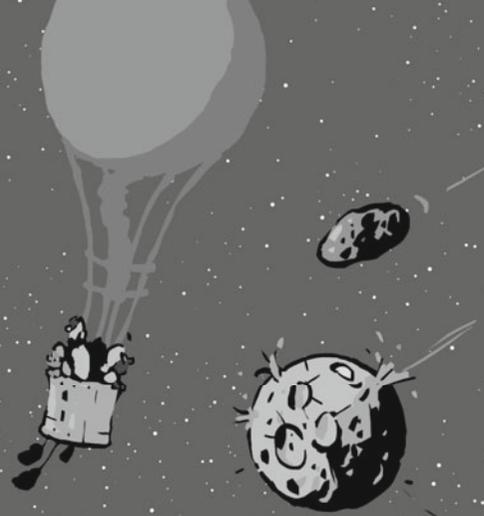
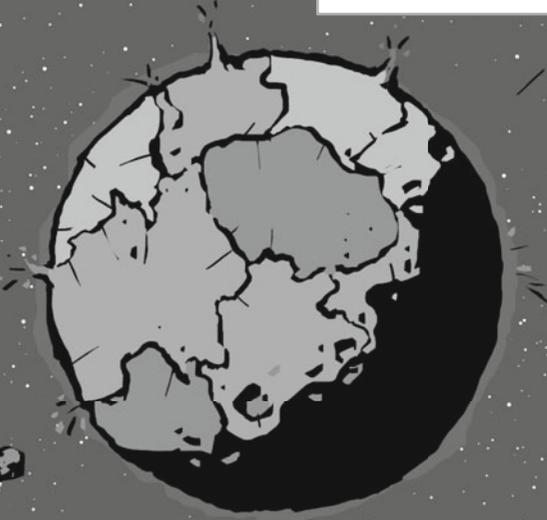
4.6 bya    4 bya    3 bya    2 bya    1 bya    Now

THAT'S **50 MILLION**  
TIMES OLDER THAN  
GRANDPA.



IN THE EARLY DAYS IT WAS A GREAT  
**MOLTEN BALL OF LIQUID ROCK...**

... WHICH BELCHED OUT **HOT GASES** AND **WATER VAPOR**  
TO FORM THE EARLY **ATMOSPHERE** AND **OCEANS.**



**PRIMITIVE LIFE FORMS** APPEARED IN THE OCEANS  
SOMETIME WITHIN THE FIRST **BILLION YEARS.**

4.6 bya

Now

WHAT DO YOU  
CALL A SINGLE-CELLED  
ORGANISM **FLOATING IN**  
A PRIMORIDAL SEA?

**BOB.**



WHAT DO YOU  
CALL A SINGLE-CELLED  
ORGANISM **SHAPED**  
LIKE A TUBE?

**ROD.**



YOU AND YOUR  
JOKES ARE SO  
**PRIMITIVE!**



THEN, AFTER **HUNDREDS OF MILLIONS OF YEARS OF EVOLUTION...**

4.6 bya

Now

WHAT DO YOU CALL A SINGLE-CELLED ORGANISM THAT LIVES IN YOUR MAILBOX?

**BILL.**



WHAT DO YOU CALL A SINGLE-CELLED ORGANISM SMEARED ON THE WALL?

**ART.**



WILL YOU TWO SHUT UP!

I'M TRYING TO CONCENTRATE!

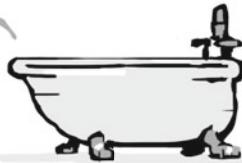


... SOME OF THESE ORGANISMS FIGURED OUT OXYGENIC **PHOTOSYNTHESIS...**

**EUREKA!**



E EK!  
HARRIET,  
PUT ON SOME CLOTHES!



... WHICH IS THE **CHEMICAL REACTION** THAT ALLOWS **GREEN THINGS** LIKE **PLANTS** AND **ALGAE** TO GROW.

IT TURNS  
SUNLIGHT, WATER, AND  
CARBON DIOXIDE...

... INTO THINGS LIKE  
BROCCOLI AND  
BEAN SPROUTS.

GREEN THINGS ARE  
THE **BASE** OF THE  
**FOOD CHAIN.**

OH **GREAT.**

WITHOUT **THEM**  
THERE COULD BE  
NO **US.**



**NOWADAYS, GREEN THINGS PLAY A KEY ROLE IN THE CARBON CYCLE...**



IN CHAPTER 4 WE'LL SEE THE INFLUENCE OF HUMAN ACTIVITY.

EVERY YEAR ABOUT **80 BILLION TONS** OF ATMOSPHERIC CARBON DISSOLVES IN SEAWATER...

... AND ABOUT THAT MUCH RETURNS TO THE ATMOSPHERE THROUGH **OUTGASSING**.

MEANWHILE, ABOUT **120 BILLION TONS** GETS SUCKED IN BY **PLANTS** THROUGH **PHOTOSYNTHESIS**...

... AND ABOUT THAT MUCH RETURNS TO THE ATMOSPHERE THROUGH **FIRE, DECOMPOSITION, AND RESPIRATION** BY PLANTS AND ANIMALS.

AND THERE'S LOTS MORE, LIKE MIXING BETWEEN THE **SURFACE OCEAN** AND THE **DEEP OCEAN**.

... WHICH IS CRUCIAL TO **ALL LIFE ON EARTH.**

YOU ARE WHAT YOU EAT!



Mostly Water and Carbon



Mostly Water and Carbon



Mostly Water and Carbon

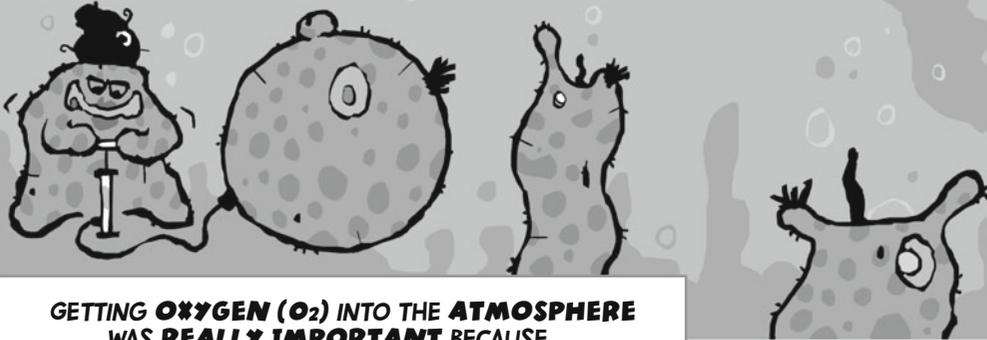
**BETWEEN ABOUT 2.8 AND 2.3 BILLION YEARS AGO, HOWEVER, GREEN THINGS DID SOMETHING PERHAPS EVEN MORE IMPORTANT.**

4.6 bya

Now

THEY PUMPED LOTS AND LOTS OF **OXYGEN** INTO THE ATMOSPHERE.

GREEN SLIME IS **GROSSLY** UNDERAPPRECIATED.



**GETTING OXYGEN (O<sub>2</sub>) INTO THE ATMOSPHERE WAS REALLY IMPORTANT BECAUSE...**

**DUH!** BECAUSE **ANIMALS** NEED OXYGEN TO BREATHE.

WELL, THAT'S TRUE...

... BUT THIS WAS A BILLION YEARS BEFORE ANIMALS.

**... BECAUSE IT LED TO THE CREATION OF A LAYER OF OZONE (O<sub>3</sub>) ABOUT 15 MILES ABOVE THE SURFACE OF THE PLANET.**

WHAT'S SO IMPORTANT ABOUT THAT?

WELL, **DUH.**

TURN THE PAGE TO FIND OUT.

OZONE LAYER

**BEFORE THE OZONE LAYER,  
LIFE HAD TO HIDE FROM THE SUN.**

4.6 bya

Now



THE SUN GENERATES  
VISIBLE LIGHT...

... BUT IT ALSO GENERATES  
DEADLY ULTRAVIOLET  
RADIATION.

THAT'S WHY WE LIVE  
UNDERWATER OR  
UNDER ROCKS.



**AFTER THE OZONE LAYER, THE  
SUN'S DEADLIEST UV RAYS GOT BLOCKED...**

4.6 bya

Now

OZONE IS LIKE  
SUNSCREEN  
FOR THE ENTIRE  
PLANET.



**... AND THAT ALLOWED LIFE TO MOVE INTO THE SUNSHINE.**

**EUREKA!**



NO, HARRIET,  
NOT AGAIN!



**NO WONDER EVERYBODY GOT WORRIED WHEN SCIENTISTS DISCOVERED  
A HOLE IN THE OZONE LAYER IN THE 1980s.**

DESPITE WHAT MANY PEOPLE THINK, THE OZONE HOLE IS **NOT** CLOSELY RELATED TO GLOBAL WARMING...

ENVIRONMENTAL PROBLEMS ARE **NOT** ALL THE SAME...

... AND YOU CAN'T SOLVE THEM ALL BY **RECYCLING.**

... BUT IT IS VALUABLE TO **COMPARE** AND **CONTRAST** THE TWO ISSUES...

THE OZONE HOLE IS RELATED TO HUMAN EMISSIONS OF **OZONE-DESTROYING** GASES SUCH AS **CHLOROFLUOROCARBONS (CFCs)**.

GLOBAL WARMING IS RELATED TO HUMAN EMISSIONS OF **GREENHOUSE** GASES SUCH AS **CARBON DIOXIDE (CO<sub>2</sub>)**.

... AND WE CAN TAKE HEART FROM THE **PROGRESS** WE'VE MADE IN REPAIRING THE OZONE HOLE,

PRESIDENT REAGAN SIGNED THE **MONTREAL PROTOCOL** THAT HELPED PHASE OUT CFCs...

... AND THE OZONE LAYER IS **RECOVERING.**

IF ONLY GLOBAL WARMING WERE SO **EASY!**

BUT LET'S GET BACK TO THE **HISTORY OF PLANET EARTH...**

**THE PAST BILLION YEARS HAVE SEEN  
WILD CHANGES IN THE CLIMATE.**

4.6 bya

Now

**THE ONLY THING  
PERMANENT IS  
CHANGE.**



**THERE WERE TIMES WHEN  
ICE COVERED ALMOST EVERYTHING...**

**THIS SNOWBALL  
EARTH IS FREEZING!**



**GOOD THING THERE  
WEREN'T ACTUALLY  
PEOPLE BACK THEN.**

**...AND TIMES WHEN  
THE NORTH POLE WAS TROPICAL.**

**BOY, I COULD  
REALLY USE SOME  
ICED TEA!**



**SORRY,  
THERE'S  
NO ICE.**



**GOOD THING THERE  
WEREN'T ACTUALLY  
PEOPLE BACK THEN.**



OF CENTRAL IMPORTANCE TO OUR STORY IS THE **CARBONIFEROUS PERIOD**, SOME **360–300 MILLION YEARS AGO**.

4.6 bya

Now

**GIANT BUGS!**

**GIANT REPTILES!**

**GIANT FERNS!**

**BUT STILL NO PEOPLE.**

SOME OF THE ORGANISMS THAT **DIED** THEN GOT BURIED...

WHAT DO YOU CALL A SINGLE-CELLED ORGANISM LYING IN A HOLE?

**DOUG.**

... AND COOKED UNDERGROUND FOR **HUNDREDS OF MILLIONS OF YEARS...**

**KNOCK KNOCK**    **WHO'S THERE?**

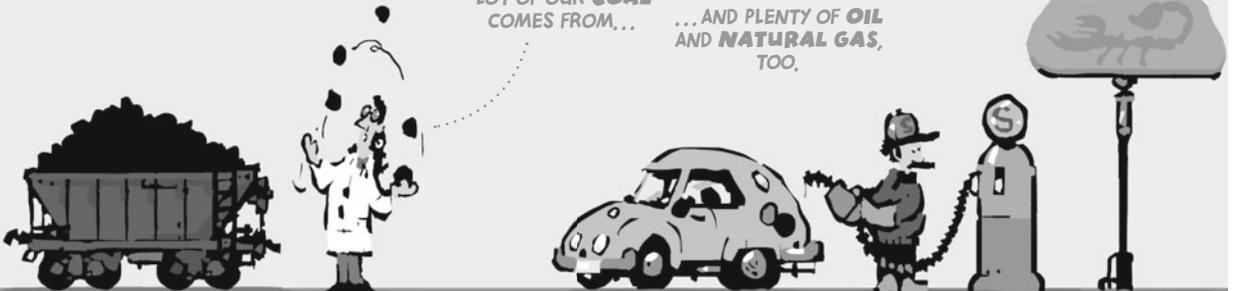
**OIL.**    **OIL WHO?**

**OIL BE BACK.**

... AND EVENTUALLY TURNED INTO **CARBON-BASED FOSSIL FUELS.**

THAT'S WHERE A LOT OF OUR **COAL** COMES FROM...

... AND PLENTY OF **OIL** AND **NATURAL GAS**, TOO.



**DURING THE LAST 100 MILLION YEARS...**

4,6 bya

4 bya

3 bya

2 bya

1 bya



100 mya

80 mya

60 mya

40 mya

20 mya

Now

**... THE CONTINENTS SLOWLY DRIFTED INTO THE POSITIONS THEY HAVE TODAY...**



CONTINENTS MOVE AT ABOUT THE SPEED THAT YOUR FINGERNAILS GROW...

... ABOUT 100 MILES EVERY MILLION YEARS.



**... AND SPECIES EITHER DIED OFF OR SLOWLY EVOLVED INTO THE FORMS THEY HAVE TODAY.**

THANKS TO AN ASTEROID 65 MILLION YEARS AGO...

... IT WAS GOODBYE VELOCIRAPTOR...

... AND HELLO CHICKEN.



100 mya

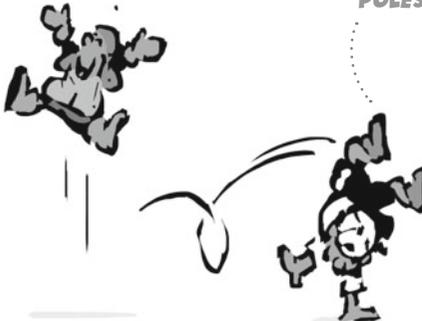
Now

**EVEN MORE RECENTLY, THE EARTH'S CLIMATE HAS CALMED DOWN A BIT...**

**... BUT CALM IS A RELATIVE TERM.**

30 MILLION YEARS WITH NO SNOWBALL EARTHS...

... AND NO TROPICAL NORTH POLES!



LOOK, WE'VE CALMED DOWN!

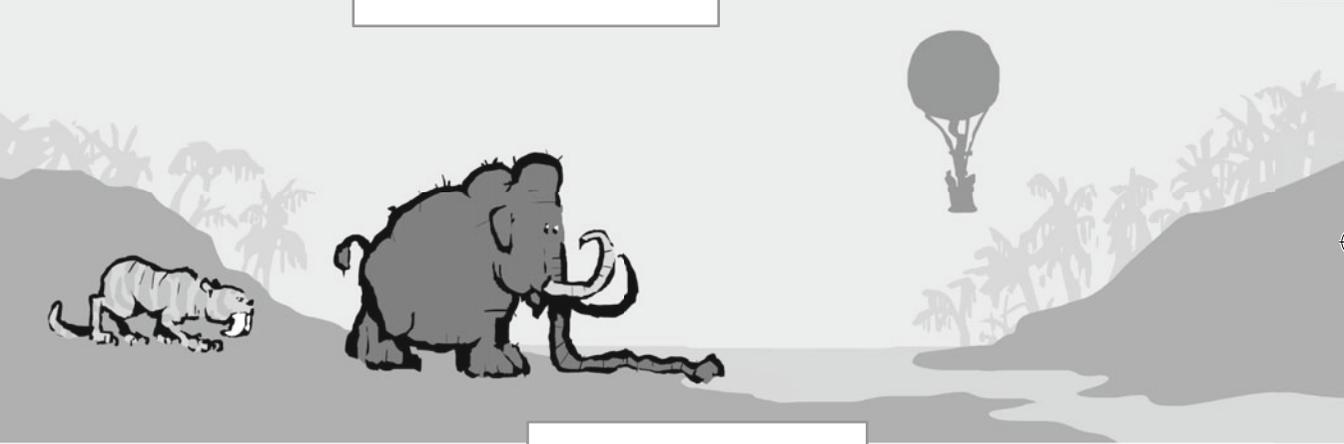
WOW, WHAT WERE YOU LIKE BEFORE?



IN PARTICULAR, OVER THE PAST **2.6 MILLION YEARS** THE PLANET HAS GONE THROUGH **REPEATED CYCLES...**



...OF **WARM PERIODS...**



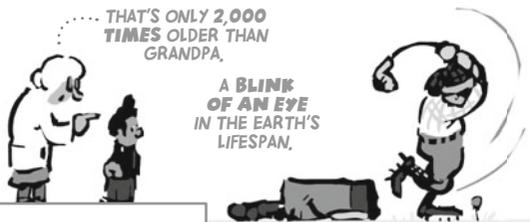
...AND **COOL PERIODS.**

SCIENTISTS CALL THEM **GLACIAL PERIODS.**

EVERYONE ELSE CALLS THEM **ICE AGES.**



FINALLY, ABOUT 200,000 YEARS AGO...

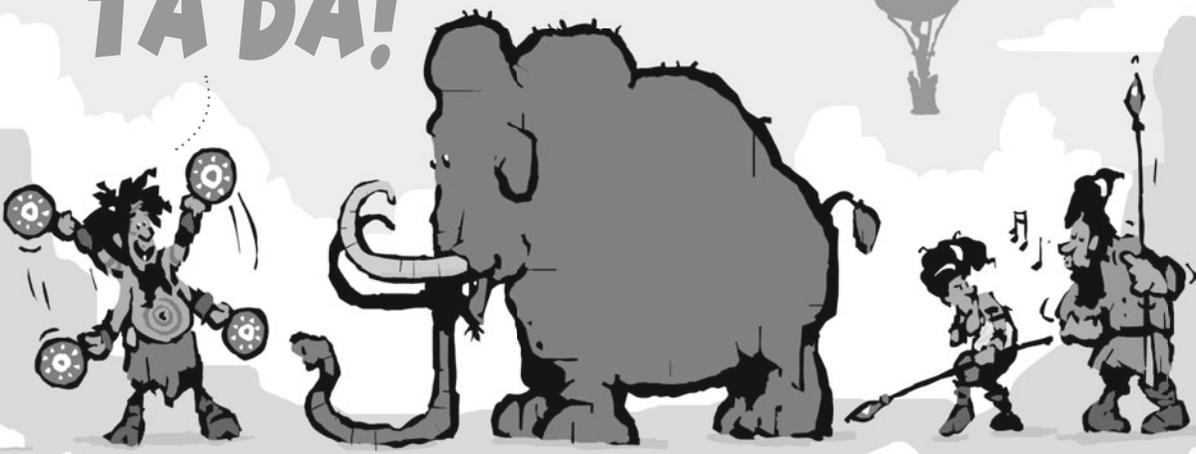


THAT'S ONLY 2,000 TIMES OLDER THAN GRANDPA.

A BLINK OF AN EYE IN THE EARTH'S LIFESPAN.

...ANATOMICALLY MODERN HUMAN BEINGS APPEARED IN AFRICA.

TA DA!



IT WASN'T LONG BEFORE THEY STARTED ASKING TOUGH QUESTIONS.



I WONDER HOW I CAN AVOID BEING EATEN?

I WONDER WHERE I CAN FIND SOME HOT SAUCE?

I WONDER WHAT CAUSED THE ICE AGES?

# CHAPTER 3

## THE ICE AGES

GO BACK 15,000 YEARS  
AND THIS WAS UNDER  
A MILE OF ICE!

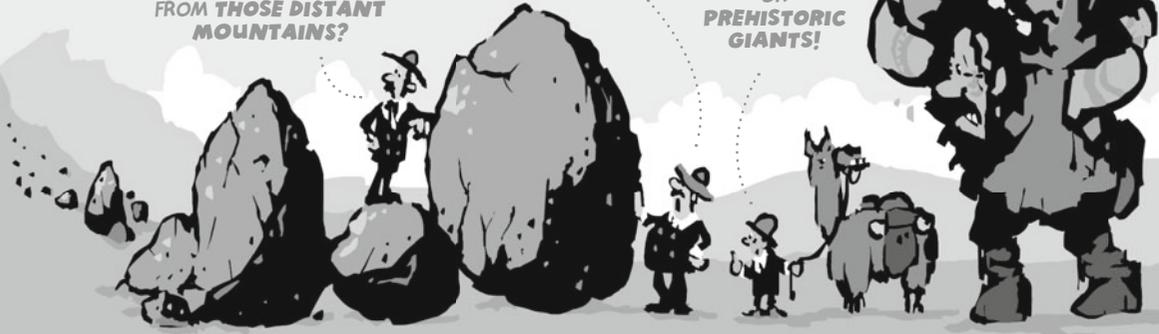


EARLY GEOLOGISTS HYPOTHESIZED THAT THERE **MUST** HAVE BEEN ICE AGES.

WHAT COULD HAVE CARRIED THESE GIANT ROCKS HERE FROM THOSE DISTANT MOUNTAINS?

THERE MUST HAVE BEEN MASSIVE GLACIERS!

OR PREHISTORIC GIANTS!



20TH CENTURY SCIENTISTS **CONFIRMED** THIS BY STUDYING EARTH'S TWO REMAINING **GIANT ICE SHEETS**.

ONE'S OVER ANTARCTICA...

... THE OTHER'S OVER GREENLAND.



THESE ICE SHEETS WERE BUILT UP OVER HUNDREDS OF THOUSANDS OF YEARS.

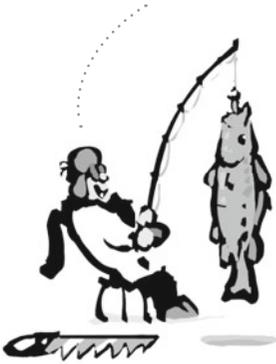


**COMPRESSED,**  
TRAPPING ANCIENT AIR  
IN ANCIENT ICE.

**BY DRILLING DOWN THROUGH THAT ICE...**

**... AND ANALYZING THE VARIOUS LAYERS...**

I'VE GOT A 6-FOOT COD!



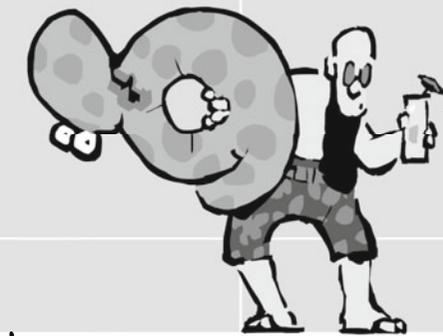
I'VE GOT A MILE-LONG ICE CORE!



ICE CORES ARE A BIT LIKE TREE RINGS.

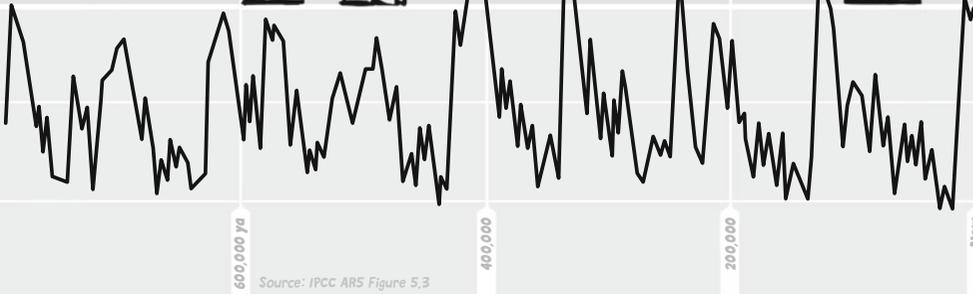


**... SCIENTISTS CAN ESTIMATE THE AVERAGE SURFACE TEMPERATURE OF PLANET EARTH FAR INTO THE DISTANT PAST.**



OVER THE PAST 800,000 YEARS THERE HAVE BEEN WARM PERIODS...

... INCLUDING THE PAST 10,000 YEARS.



Source: IPCC AR5 Figure 5.3

**THESE ICE CORES SUGGEST THAT EARTH HAS USUALLY BEEN ABOUT 6°C (11°F) COLDER THAN IT IS NOW.**

THAT DIFFERENCE IN TEMPERATURE MAY SEEM SMALL...

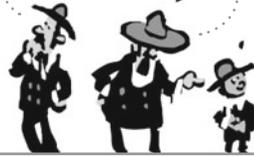
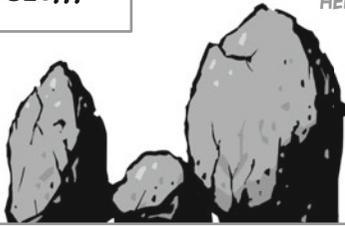
... BUT IT WAS BIG ENOUGH FOR GLACIERS TO BURY CHICAGO.



**THE MYSTERY OF THE ICE AGES...**

I WONDER WHY THERE AREN'T **GLACIERS** HERE ANYMORE?

AND DON'T SAY **PREHISTORIC GIANTS!**



... WAS MOSTLY SOLVED BY THE SERBIAN MATHEMATICIAN **MILUTIN MILANKOVITCH** DURING THE FIRST WORLD WAR.



COMPARED TO THE **MYSTERY** OF WHY WE'RE FIGHTING THIS **DUMB WAR...**

... THIS IS **CHILD'S PLAY.**



HE STUDIED THE **DETAILS** OF THE EARTH'S **ORBIT AROUND THE SUN...**



IT ORBITS ONCE A YEAR...

... BUT OVER THE YEARS IT **MEANDERS** AND **WOBBLES** A BIT.



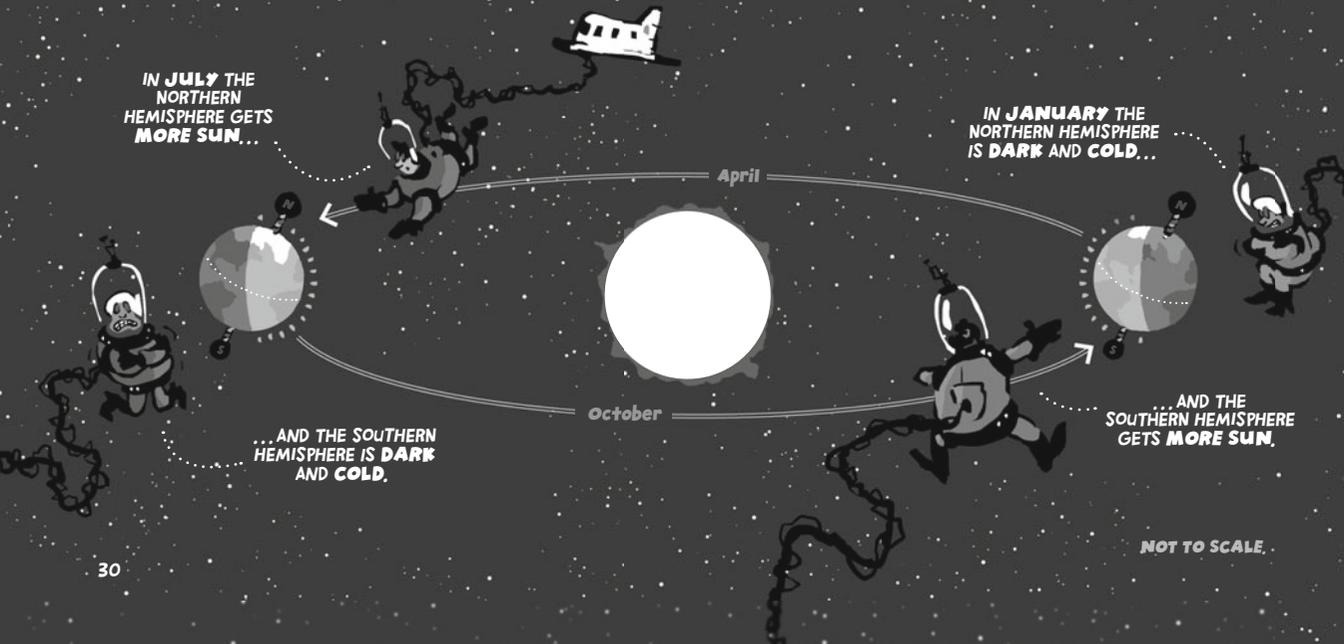
... INCLUDING THE **TILT** OF THE EARTH, WHICH CAUSES **WINTERS** AND **SUMMERS.**

IN **JULY** THE NORTHERN HEMISPHERE GETS **MORE SUN...**

IN **JANUARY** THE NORTHERN HEMISPHERE IS **DARK AND COLD...**

... AND THE SOUTHERN HEMISPHERE IS **DARK AND COLD.**

... AND THE SOUTHERN HEMISPHERE GETS **MORE SUN.**



NOT TO SCALE.

IT TURNS OUT THAT THE TILT **VARIABLES** OVER TENS OF THOUSANDS OF YEARS.

AND NOW, IN **ASTRONOMY NEWS**, THE TILT OF THE EARTH IS **23.4 DEGREES** AND SLOWLY GETTING **WEAKER**.

WE'LL HAVE AN UPDATE IN THE YEAR **11,000**.



WHEN THE TILT IS STRONGER, **SEASONS ARE STRONGER...**

MY HEAD IS **ON FIRE...**  
... AND MY FEET ARE **FREEZING!**



MY HEAD IS **FREEZING...**  
... AND MY FEET ARE **ON FIRE!**



... AND WHEN THE TILT IS WEAKER, **SEASONS ARE WEAKER.**

I'M GETTING **COOKED** A MORE **EVEN AMOUNT** ALL AROUND...



... NO MATTER WHAT TIME OF YEAR IT IS,



**TWO OTHER ORBITAL VARIATIONS** ALSO AFFECT THE STRENGTH OF THE SEASONS.

IN ADDITION TO TILT, THERE'S **ECCENTRICITY** AND **PRECESSION...**

... BUT YOU CAN THINK OF THEM AS **WIGGLES** AND **JIGGLES.**



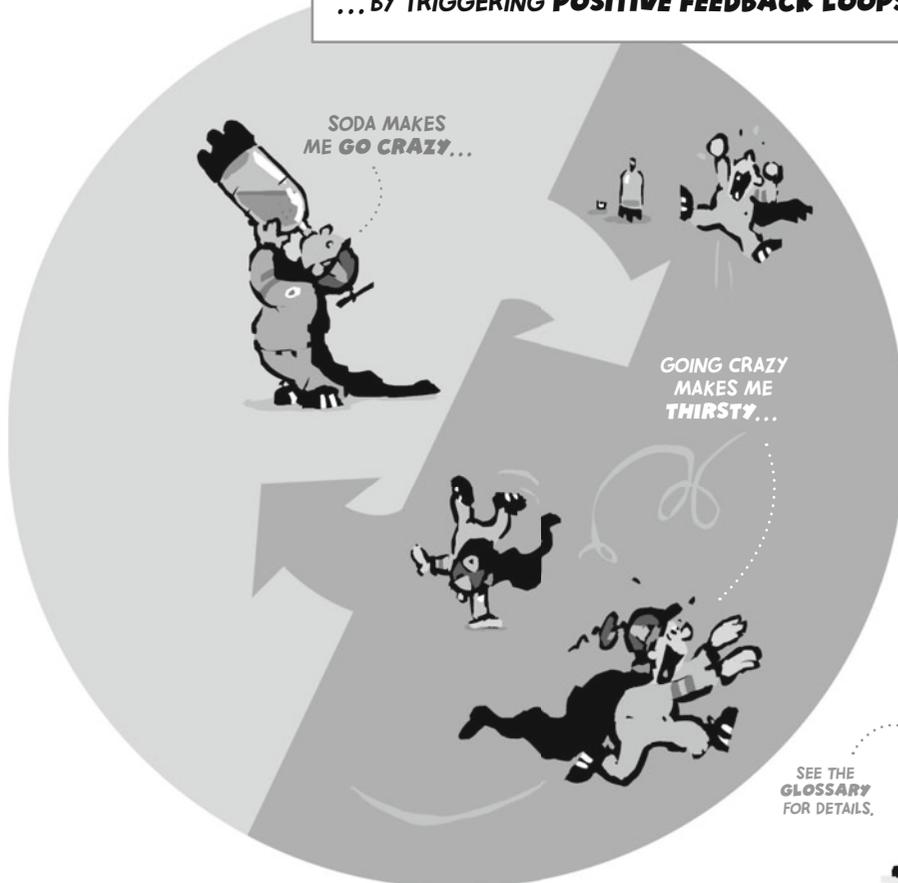
THE **MILANKOVITCH CYCLE** THEORY SAYS THAT THESE THREE ORBITAL VARIATIONS...



... SET THE **RHYTHM** FOR THE ICE AGES...



... BY TRIGGERING **POSITIVE FEEDBACK LOOPS.**



POSITIVE FEEDBACK LOOPS **AMPLIFY** CHANGES...

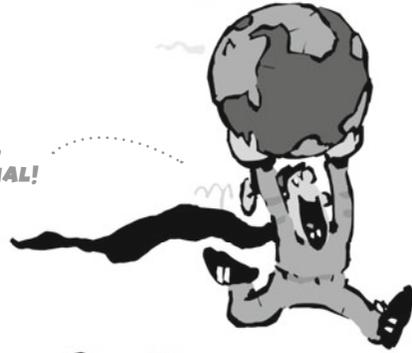
... SO THAT **CRAZY** TURNS INTO **EVEN MORE CRAZY.**

SEE THE **GLOSSARY** FOR DETAILS.



SOMETIMES THOSE POSITIVE FEEDBACK LOOPS  
BRING THE EARTH **OUT OF AN ICE AGE...**

I'M GOING  
INTERGLACIAL!



... AND SOMETIMES THEY SEND US **BACK INTO ONE.**

GETTING  
SLEEPY...



... MAKES ME  
EVEN MORE  
SLEEPY.



ZZZZZZZ.



LET'S SEE HOW IT WORKS IN **CLOSER DETAIL.**

FOR  
A **SIMPLIFIED**  
**VERSION** OF  
THE **MILANKOVITCH**  
STORY...

FOR MORE DETAILS, SEE  
**MILANKOVITCH** IN  
THE GLOSSARY...



... OR READ MY  
626-PAGE BOOK!

... IMAGINE WE'RE IN **CANADA** DURING A **GLACIAL PERIOD**.

LIKE THE ONE THAT  
PEAKED **20,000**  
**YEARS** AGO.



THE **MILANKOVITCH** CYCLES EVENTUALLY CREATE  
CONDITIONS WITH **STRONG SEASONS**.

**HOT HOT** SUMMERS.

LOTS OF **MELTING**  
**ICE** AND **SNOW**.



**COLD COLD** WINTERS.

BUT THERE ISN'T ENOUGH  
**NEW SNOW** TO KEEP UP  
WITH THE **SUMMER MELT**.



THAT CAUSES **ICE** AND **SNOW** TO SLOWLY GIVE WAY TO **LAND** AND **WATER**.

NOW WE CAN  
PLANT **MAPLE**  
**SYRUP** TREES!



**AMPLIFYING THE MILANKOVITCH CYCLES ARE THINGS LIKE THE ICE-ALBEDO EFFECT...**



ICE AND SNOW **REFLECT** LOTS OF SUNLIGHT BACK INTO SPACE.

LAND AND WATER **ABSORB** MORE SUNLIGHT.

**... WHICH CREATE POSITIVE FEEDBACK LOOPS...**

MELTING ICE AND SNOW LEADS TO **HIGHER TEMPERATURES...**



**HIGHER TEMPERATURES MELT ICE AND SNOW...**

**WARMING TURNS INTO EVEN MORE WARMING.**

**... THAT BRING ABOUT A GLOBAL INTERGLACIAL PERIOD.**



IT SURE IS **HOT AND LOUD** IN HERE!

**WHAT?**

TO SEE HOW IT WORKS IN THE OTHER DIRECTION,  
IMAGINE WE'RE IN THE MIDDLE OF AN **INTERGLACIAL PERIOD**.

LIKE THE ONE  
WE'RE IN **NOW**.



THE MILANKOVITCH CYCLES EVENTUALLY CREATE CONDITIONS WITH **MILD SEASONS**.

**MILD SUMMERS.**

NOT MUCH  
MELTING ICE  
AND SNOW.

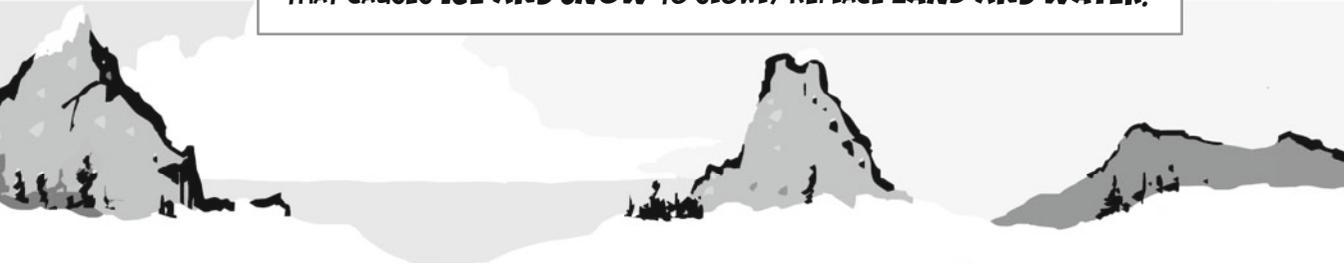


**MILD WINTERS.**

BUT STILL COLD  
ENOUGH FOR SNOW  
IN PLACES LIKE  
**CANADA**.



THAT CAUSES **ICE AND SNOW** TO SLOWLY REPLACE **LAND AND WATER**.



WHAT'S MORE CANADIAN  
THAN **MAPLE SYRUP?**

**ICE HOCKEY!**



NOW THINGS LIKE THE **ICE-ALBEDO EFFECT** WORK IN THE **OTHER DIRECTION...**

LAND AND WATER  
THAT USED TO  
**ABSORB** LOTS  
OF SUNLIGHT...

... GET COVERED WITH  
ICE AND SNOW THAT  
**REFLECT** SUNLIGHT,

... **CREATING POSITIVE FEEDBACK LOOPS THAT COOL THE PLANET.**

MORE ICE AND SNOW  
**LOWERS**  
TEMPERATURES...

LOWER  
TEMPERATURES  
MEAN **MORE ICE**  
AND SNOW...

**COOLING** TURNS  
INTO **EVEN MORE**  
COOLING.

ALL THIS BRINGS UP A **PRETTY OBVIOUS QUESTION.**

GIVEN THAT WE'RE  
**CURRENTLY** IN AN  
**INTERGLACIAL**  
PERIOD...

... SHOULD WE  
WORRY ABOUT THE  
**NEXT ICE AGE?**

THE **ANSWER** IS THAT MOTHER NATURE **IS**  
GEARING UP FOR **ANOTHER ICE AGE...**

... BUT NOT FOR AT LEAST **30,000 YEARS.**

OH NO, WE BETTER  
STOCK UP ON  
HEATING OIL!



HA!  
**NEVER  
MIND!**



AND LONG BEFORE **THAT** HAPPENS WE'RE GOING TO HAVE TO COME  
TO TERMS WITH WHAT **WE'RE** DOING TO THE CLIMATE,



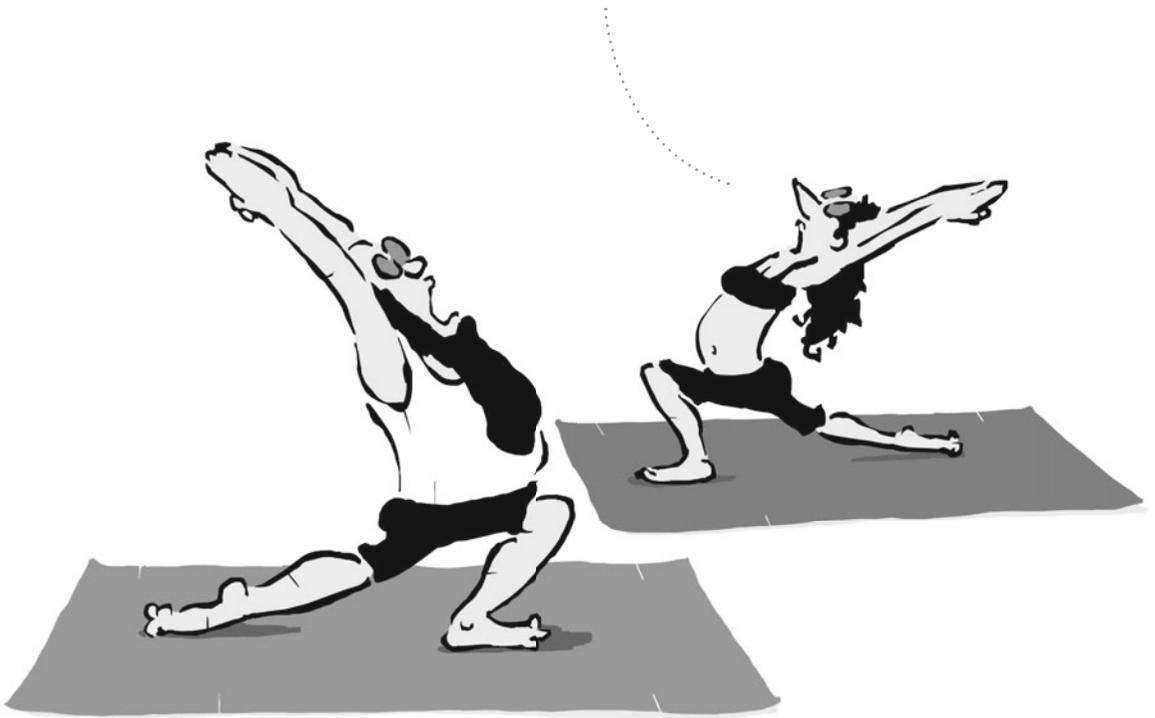
UM, ABOUT THAT  
HEATING OIL...

# CHAPTER 4

## CARBON DIOXIDE

EMPTY YOUR  
MIND ...

... AND FOCUS ON  
SOMETHING **ODORLESS,**  
**COLORLESS,** AND  
**INVISIBLE,**



WHAT WE CALL **AIR** IS ACTUALLY A MIXTURE THAT'S ABOUT **21% OXYGEN...**

...AND ABOUT **78% NITROGEN.**

CREATED OVER THE EONS BY ALL THAT PHOTOSYNTHESIZING GREEN STUFF.



THE **REMAINING 1%** INCLUDES **WATER VAPOR...**



...AND RELATIVELY **TINY AMOUNTS** OF OTHER GASES...

...INCLUDING **CARBON DIOXIDE (CO<sub>2</sub>).**

AIR IS ONLY ABOUT **0.04% CO<sub>2</sub>...**

... BUT THAT STILL EQUALS ABOUT **4,000,000,000,000,000,000** MOLECULES OF **CO<sub>2</sub>** IN EVERY BREATH YOU TAKE.



IN THE EARLY 1950s A CHEMIST NAMED  
**CHARLES DAVID KEELING...**



CALL ME  
**DAVE.**

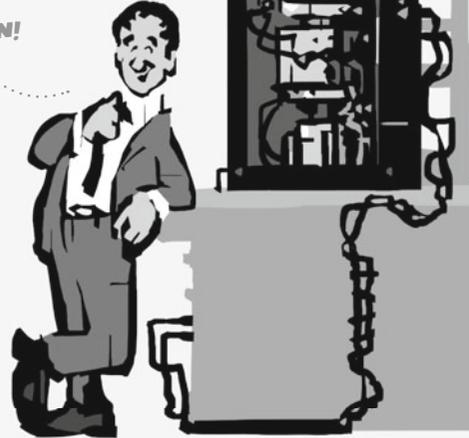


... FIGURED OUT A WAY TO ACCURATELY MEASURE  
**THE CONCENTRATION OF CARBON DIOXIDE IN AIR.**

WHAT'S THE **CO<sub>2</sub>**  
**DIFFERENCE**  
BETWEEN THESE  
TWO SAMPLES?



**ONE IN  
A MILLION!**



STARTING IN 1958, KEELING AND HIS COLLEAGUES MADE **DAILY MEASUREMENTS**  
OF **CO<sub>2</sub>** AT THE **MAUNA LOA OBSERVATORY** IN HAWAII...

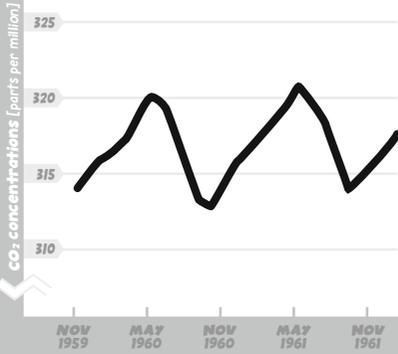
C'MON DAD, LET'S  
GO TO THE **BEACH!**

SORRY, KID,  
NOT NOW.



... AND THE RESULTS MADE HIM **FAMOUS.**

KEELING MADE **TWO BIG DISCOVERIES**. FIRST, HE DISCOVERED AN **ANNUAL CYCLE** IN CO<sub>2</sub> CONCENTRATIONS.



DUDE, IT'S LIKE THE PLANET IS **BREATHING!**

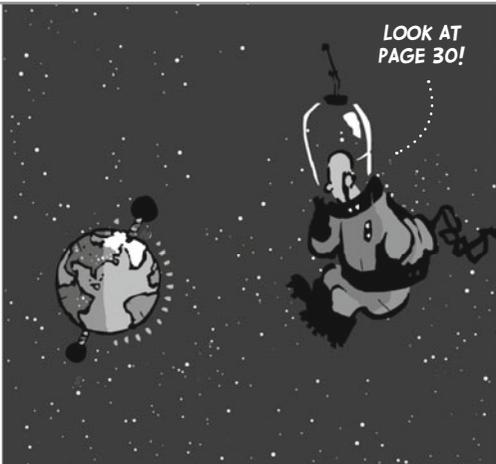
OKAY, HIPPIE, TAKE IT EASY.



Source: <http://scrippsco2.ucsd.edu>

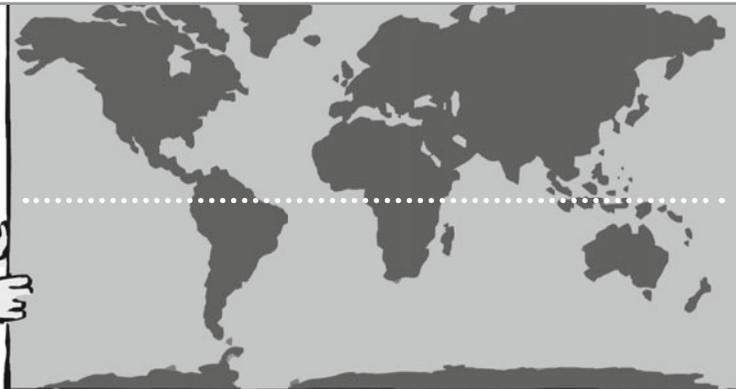
THIS CYCLE IS RELATED TO THE **SEASONS**...

...AND TO THE **CARBON CYCLE**...

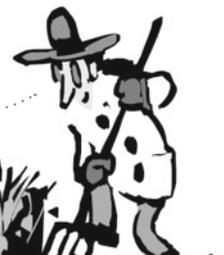


...AND TO THE FACT THAT **MOST OF THE LAND ON EARTH IS IN THE NORTHERN HEMISPHERE**.

LOOK AT A **MAP!**

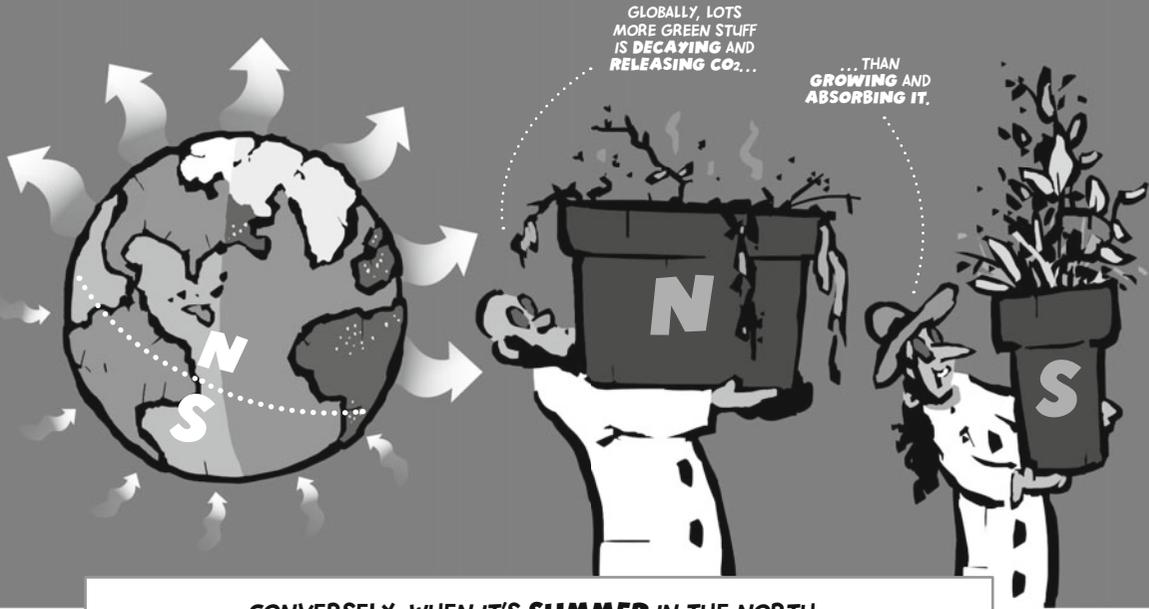


**MORE LAND MEANS MORE GREEN STUFF.**



WHEN IT'S **WINTER** IN THE NORTH,  
EXTRA CO<sub>2</sub> GETS "EXHALED" INTO THE ATMOSPHERE...

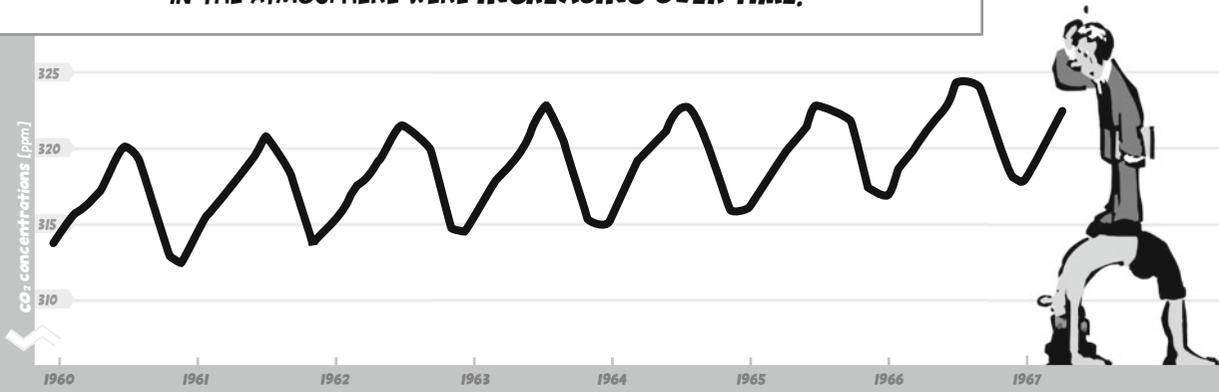
... THANKS TO PROCESSES LIKE THE **DECOMPOSITION OF FALLING LEAVES.**



CONVERSELY, WHEN IT'S **SUMMER** IN THE NORTH,  
THAT EXTRA CO<sub>2</sub> GETS "INHALED" BY **INCREASED PHOTOSYNTHESIS.**



KEELING'S **SECOND BIG DISCOVERY** WAS THAT CO<sub>2</sub> CONCENTRATIONS IN THE ATMOSPHERE WERE **INCREASING OVER TIME**.



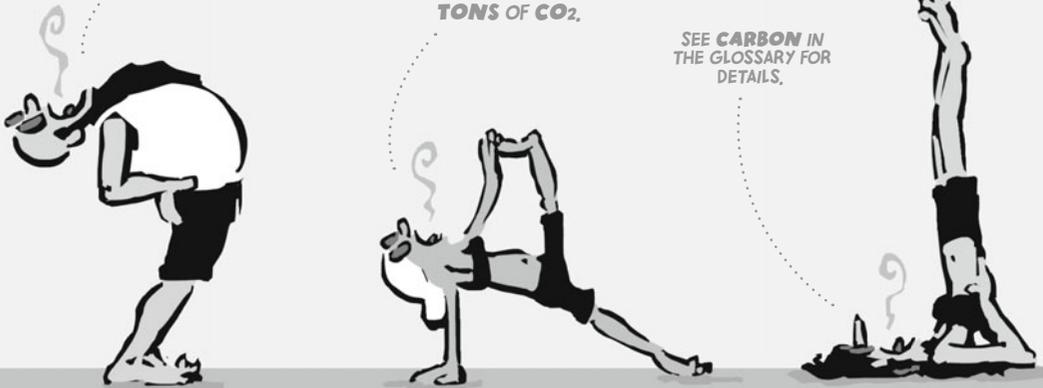
WHEN KEELING STARTED IN 1958, THE INCREASE WAS ABOUT **1 PART PER MILLION (ppm) PER YEAR**.

Source: <http://scrippsCO2.ucsd.edu>

AN INCREASE OF 1 ppm EQUALS ABOUT **2 BILLION EXTRA TONS OF CARBON...**

...OR ALMOST **8 BILLION EXTRA TONS OF CO<sub>2</sub>**.

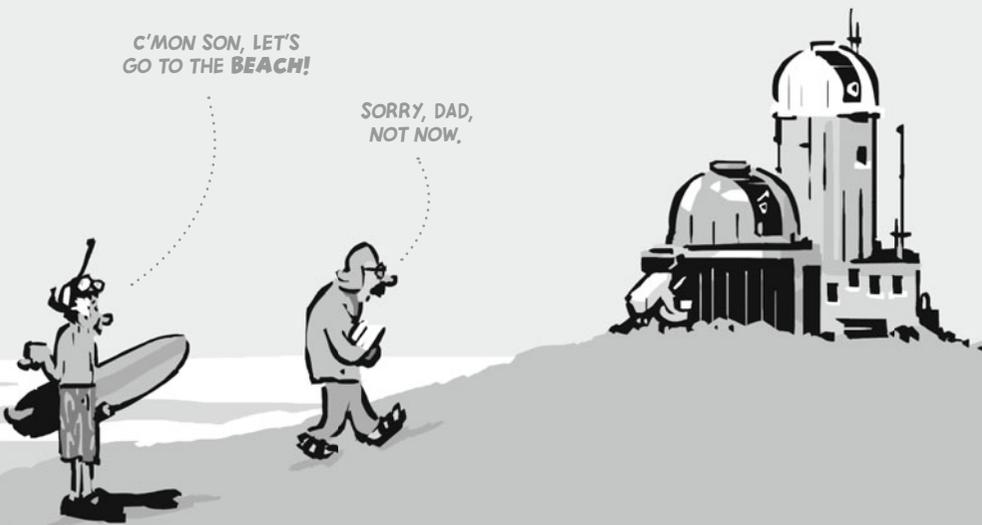
SEE **CARBON** IN THE GLOSSARY FOR DETAILS.



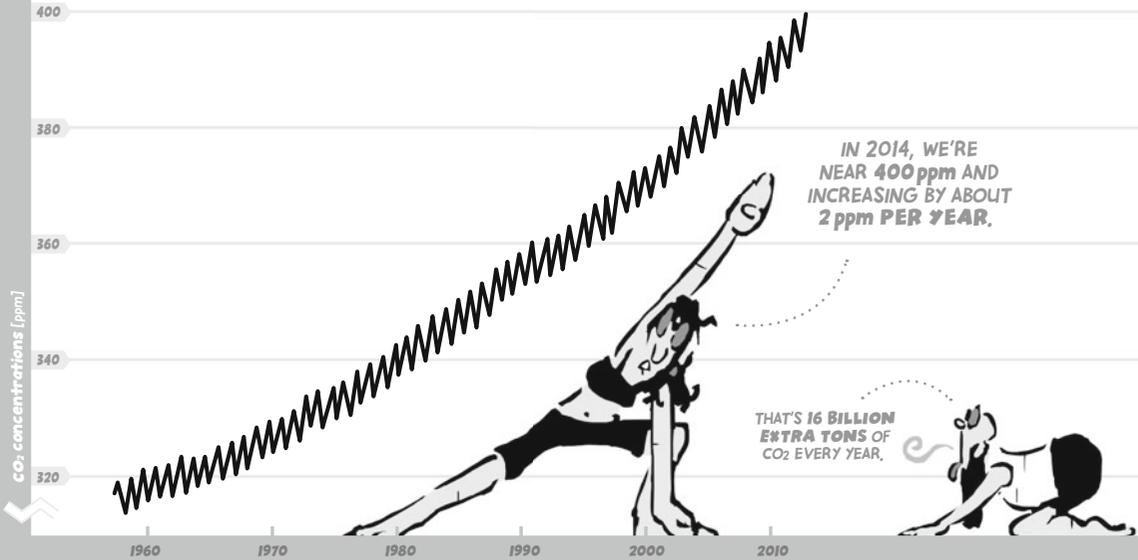
KEELING'S MEASUREMENTS CONTINUED FOR **YEARS**, AND THEN **DECADES**, AND AFTER HIS RETIREMENT HIS SON STEPPED INTO HIS SHOES.

C'MON SON, LET'S GO TO THE **BEACH!**

SORRY, DAD, NOT NOW.

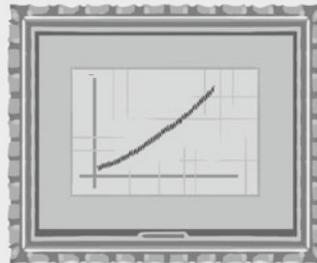


THE GRAPH OF THE DAILY MEASUREMENTS THAT THEY AND THEIR COLLEAGUES HAVE MADE SINCE 1958 IS CALLED THE **KEELING CURVE**.



IT IS NOW ONE OF THE **MOST FAMOUS IMAGES** IN THE WORLD...

Source: <http://scrippsco2.ucsd.edu>



... AND ONE OF THE CENTRAL PIECES OF **EVIDENCE** IN THIS BOOK.

WHAT DOES IT MEAN?

IT MEANS **HUMAN ACTIVITY** IS VISIBLE ON A **PLANETARY SCALE**.



IN THE 19TH CENTURY THE MAJOR SOURCE OF HUMAN CO<sub>2</sub> EMISSIONS WAS **DEFORESTATION...**

CLEARING TREES TO MAKE ROOM FOR FARMS AND CITIES...

... RELEASES THE **CARBON** THAT WAS **STORED IN THOSE TREES** INTO THE ATMOSPHERE.



... BUT NOW IT'S THE **FOSSIL FUELS** THAT PROVIDE MOST OF OUR **ELECTRICITY** AND POWER OUR **FACTORIES** AND **CARS**.



COAL-BURNING POWER PLANTS ARE THE **#1 SOURCE** OF CO<sub>2</sub>.

BY 2010 WE WERE BURNING THROUGH **43,000 GALLONS** OF PETROLEUM **EVERY SECOND**.

NATURAL GAS PRODUCTION IS GROWING THANKS TO **FRACKING**.



Source: IPCC AR5 Figure 6.8

ABOUT **60%** OF THAT EXTRA CO<sub>2</sub> GETS ABSORBED BY **PLANTS** AND **SOILS...**

... AND BY OTHER **CARBON SINKS** SUCH AS THE **OCEANS...**

FORESTS STILL COVER ABOUT **1/3** OF THE EARTH'S LAND.

WE'LL COME BACK TO THIS IN CHAPTER 15.



WE'LL COME BACK TO THIS IN CHAPTER 8, ON **OCEAN ACIDIFICATION**.



... BUT THE REST **STAYS IN THE ATMOSPHERE**, PUSHING UP THE KEELING CURVE.

HERE'S HOW THE **10 BILLION TONS** OF CARBON WE EMIT EACH YEAR AMPLIFIES THE **CARBON CYCLE**.



AS WE SAW ON PAGE 18, ABOUT **200 BILLION TONS** CYCLE NATURALLY EVERY YEAR.

BUT EVERY YEAR WE ADD ANOTHER **4 BILLION TONS** TO THE **ATMOSPHERE...**

... **3 BILLION TONS** TO THE **OCEANS...**

... AND **3 BILLION TONS** THAT ARE ABSORBED BY **PLANTS AND SOILS.**

HUMAN EMISSIONS ARE A **SMALL FRACTION** OF THE NATURAL CYCLE, BUT OVER TIME IT **ADDS UP.**

INHALE MORE THAN YOU **E#HALE...**

... AND PRETTY SOON YOUR LUNGS WILL **E#PLODE.**



SCIENTISTS HAVE ALSO PUT THE KEELING CURVE IN **HISTORICAL CONTEXT...**

... BY STUDYING THE AMOUNT OF CO<sub>2</sub> TRAPPED IN **ICE CORES.**

WHAT DID CO<sub>2</sub> CONCENTRATIONS LOOK LIKE **BEFORE 1958?**

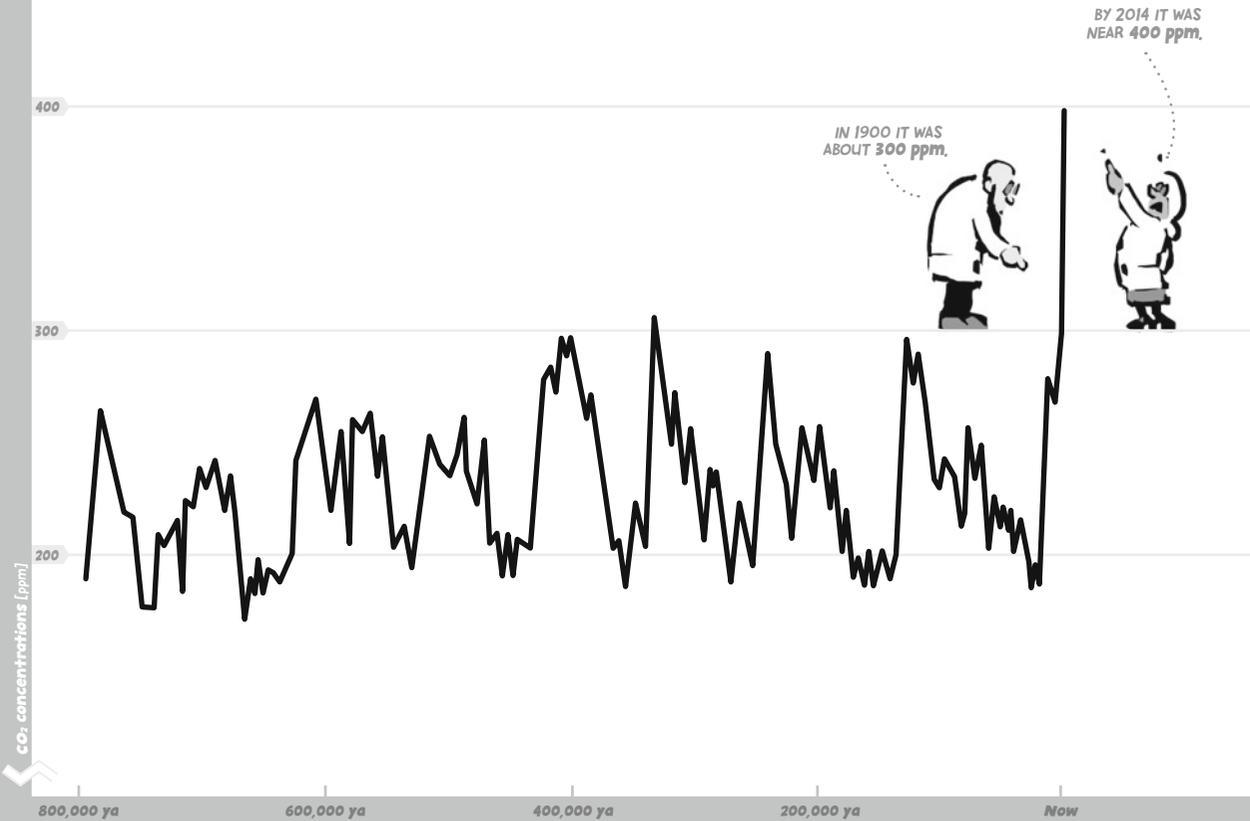
DRILL, BABY, DRILL.



THEY DISCOVERED THAT **TODAY'S LEVELS ARE OFF THE CHARTS** COMPARED TO THE LAST 800,000 YEARS.

BY 2014 IT WAS NEAR **400 ppm.**

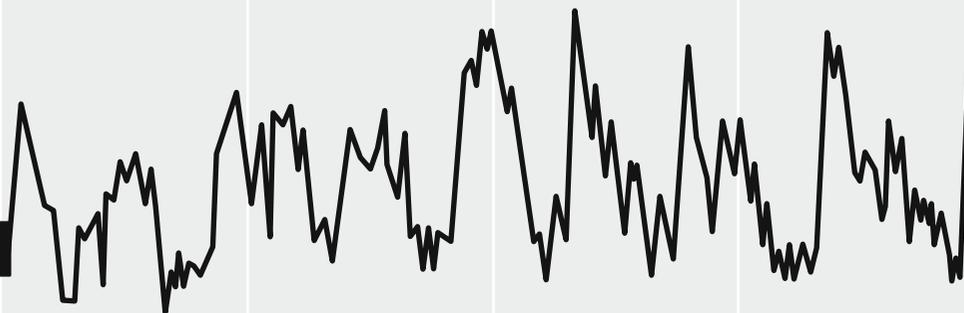
IN 1900 IT WAS ABOUT **300 ppm.**



**EVEN MORE AMAZING IS THE RELATIONSHIP BETWEEN THIS HISTORIC CO<sub>2</sub> DATA...**



CO<sub>2</sub> data



**... AND THE ICE CORE TEMPERATURE DATA FROM PAGE 29.**



temperature data



800,000 ya

600,000

400,000

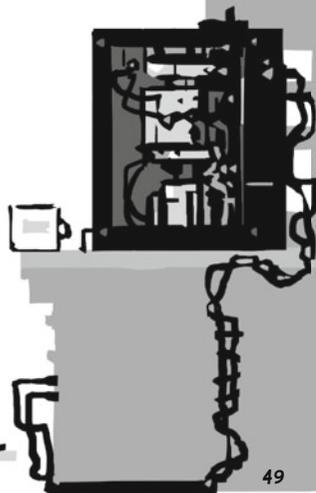
200,000

Now

**IT'S OBVIOUS THAT CO<sub>2</sub> AND TEMPERATURE HAVE BEEN CLOSELY RELATED FOR EONS.**

WHAT ARE THE ODDS OF THAT HAPPENING BY CHANCE?

LESS THAN ONE IN A MILLION!

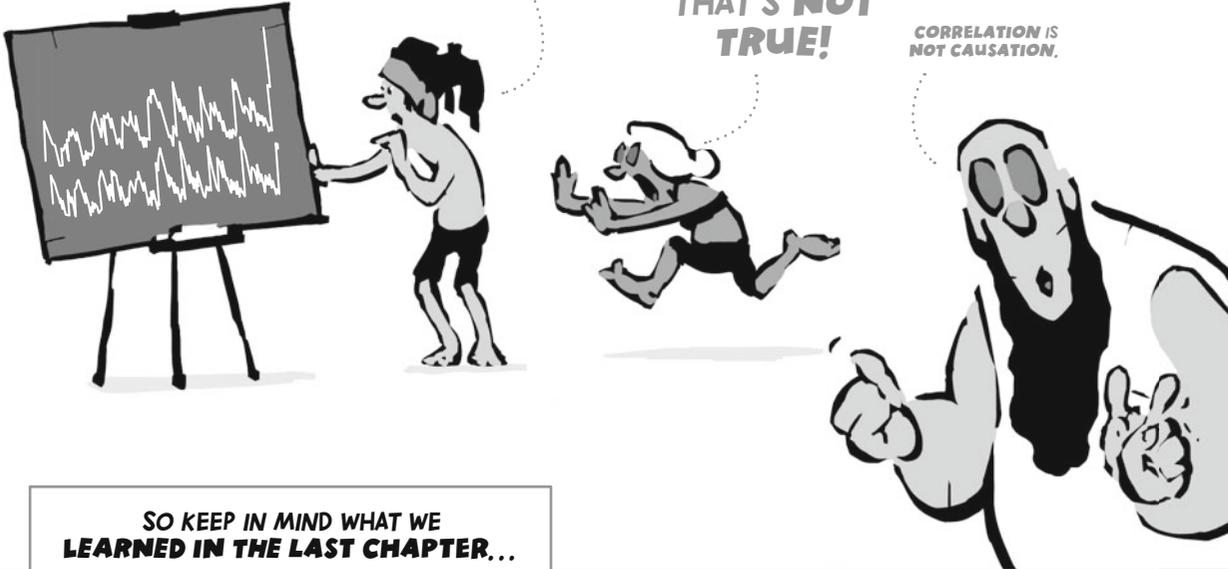


THE **CONNECTION** BETWEEN  $CO_2$  AND TEMPERATURE IS SO STRONG THAT IT'S **EASY** TO GET CARRIED AWAY.

DUDE,  $CO_2$  MUST BE THE **DRIVING FORCE** BEHIND THE ICE AGES!

BE CAREFUL, THAT'S **NOT TRUE!**

**CORRELATION IS NOT CAUSATION.**



SO KEEP IN MIND WHAT WE **LEARNED IN THE LAST CHAPTER...**

THE **MILANKOVITCH CYCLES** SET THE **TEMPO** FOR THE ICE AGES.

...AS WE MOVE ON TO THE **NEXT CHAPTER.**



**$CO_2$  AMPLIFIES THE MESSAGE!**

# CHAPTER 5

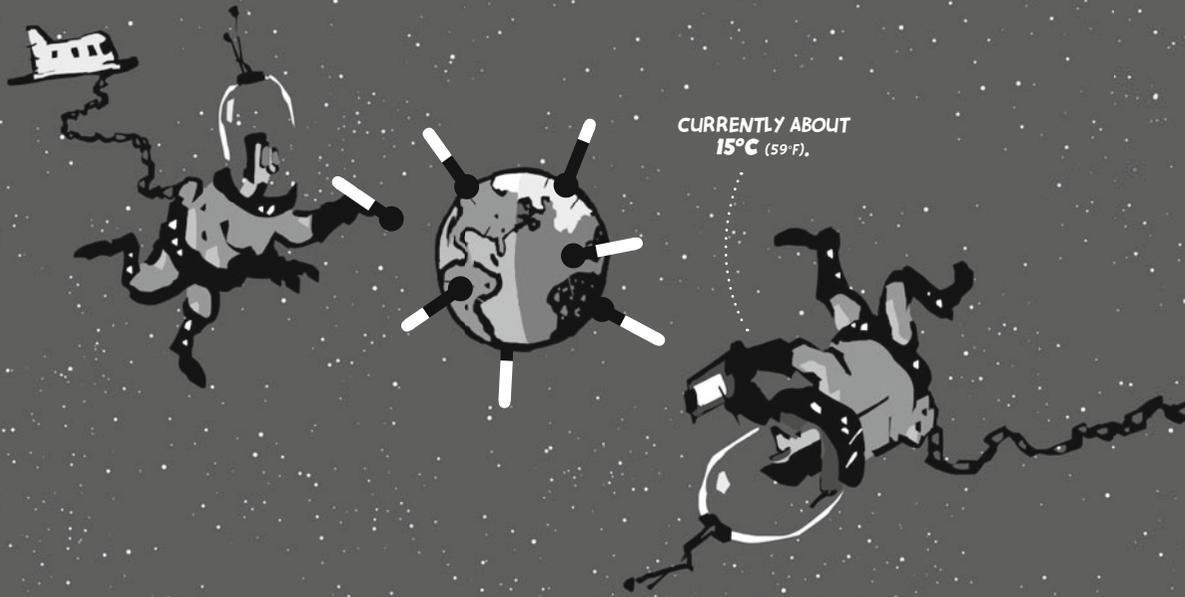
## ENERGY

YOUR **BANK ACCOUNT**  
DEPENDS ON **MONEY IN**  
AND **MONEY OUT...**

... AND THE  
**EARTH'S TEMPERATURE**  
DEPENDS ON **ENERGY IN**  
AND **ENERGY OUT.**

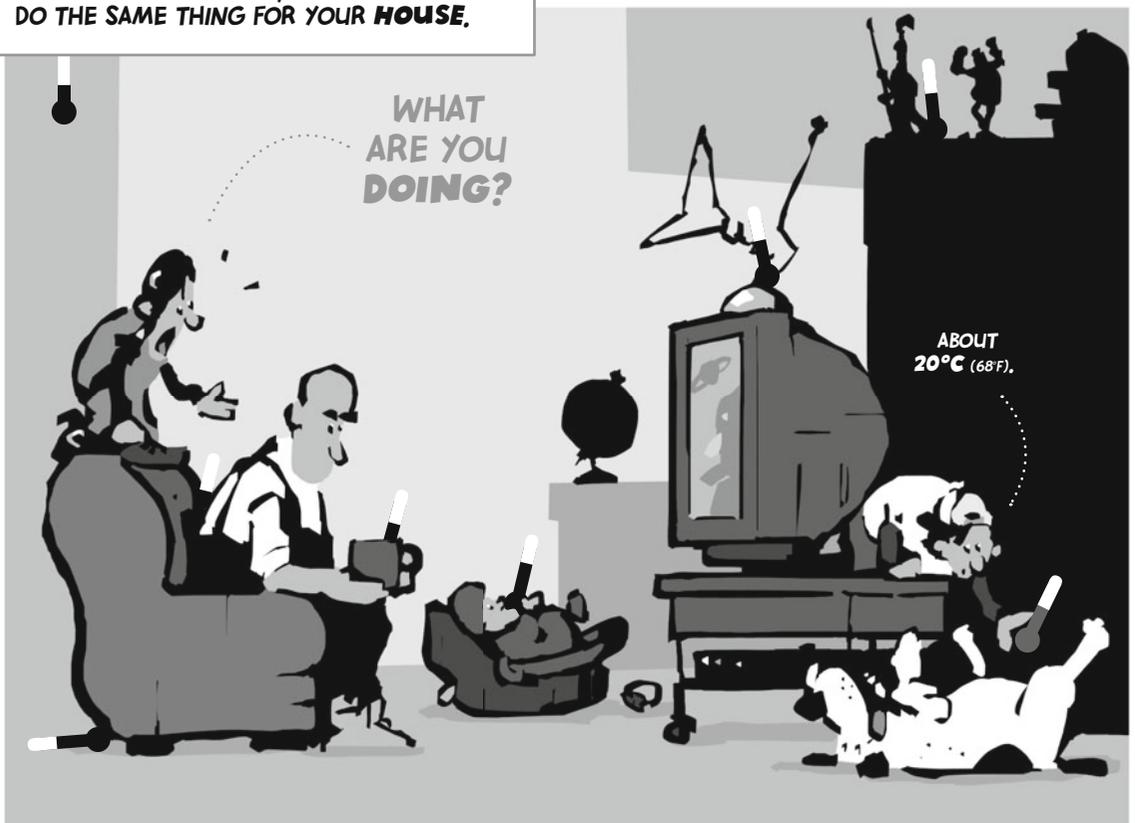


IF YOU SPEND A YEAR MEASURING AIR TEMPERATURES  
ALL OVER THE SURFACE OF THE PLANET...



... YOU CAN CALCULATE THE **GLOBAL AVERAGE TEMPERATURE** FOR PLANET EARTH.

IF YOU WANTED TO, YOU COULD  
DO THE SAME THING FOR YOUR **HOUSE**.



THE TWO DOMINANT INFLUENCES ON GLOBAL AVERAGE TEMPERATURE ARE **ENERGY IN** AND **ENERGY OUT**.



IT'S TRUE FOR YOUR HOUSE AND IT'S TRUE FOR THE **WHOLE PLANET**.



WHEN **ENERGY IN** EXCEEDS **ENERGY OUT**, THE PLANET **WARMS UP...**



JUST LIKE YOUR **HOUSE WARMS UP** WHEN YOU **TURN ON THE HEATER**,



... AND WHEN **ENERGY OUT** EXCEEDS **ENERGY IN**, THE PLANET **COOLS DOWN**.



JUST LIKE YOUR **HOUSE COOLS DOWN** WHEN YOU **OPEN A WINDOW**,



SO TO UNDERSTAND GLOBAL TEMPERATURE WE NEED TO UNDERSTAND MORE ABOUT **ENERGY IN** AND **ENERGY OUT**.

**ENERGY IN IS SIMPLE.**



IF YOU PICTURE THE SUN AS A  
**BASKETBALL** ON ONE END OF  
A FULL-SIZE COURT...

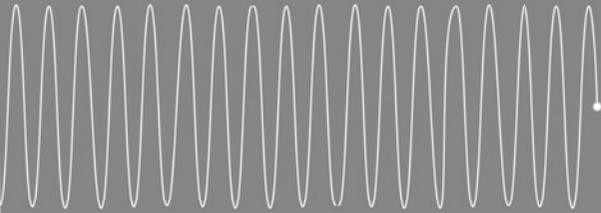
... THEN THE EARTH WOULD BE  
A **LARGE GRAIN OF SAND**  
UNDER THE OTHER BASKET.





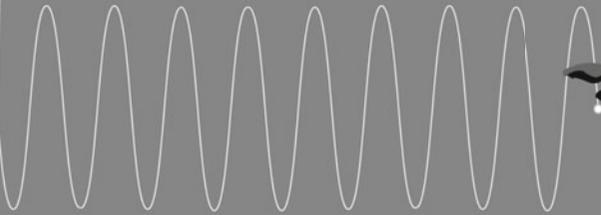
ENERGY FROM THE SUN COMES IN THE FORM OF **ELECTROMAGNETIC RADIATION**, WHICH INCLUDES...

... **ULTRAVIOLET (UV) RADIATION**, WITH SHORT, HIGH-ENERGY WAVELENGTHS...



UV IS PARTIALLY  
BLOCKED BY THE  
**OZONE LAYER**.  
(SEE PAGE 20.)

... **VISIBLE LIGHT**, WHICH COVERS THE **WHOLE RAINBOW** (LITERALLY!)...



**VISIBLE LIGHT** IS THE ONLY  
KIND OF ELECTROMAGNETIC  
RADIATION PEOPLE CAN SEE.

... AND **INFRARED (IR) RADIATION**, WITH LONG, LOW-ENERGY WAVELENGTHS.



WE'LL COME BACK TO  
THIS IN A MOMENT.

**ENERGY OUT IS MORE COMPLICATED.**

FOR EXAMPLE, IT INCLUDES  
SOLAR ENERGY THAT IS **REFLECTED BACK**  
**INTO SPACE BY CLOUDS...**

**... AND BY THE EARTH'S SURFACE.**

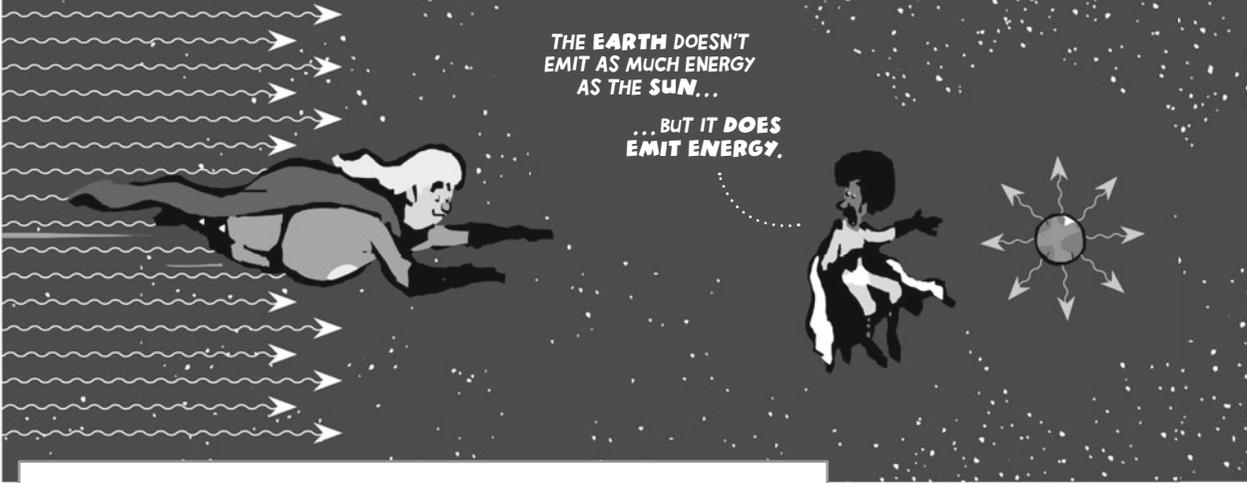
**IT'S  
ALBEDO!**

ABOUT 30% OF ALL  
INCOMING ENERGY IS  
REFLECTED BY CLOUDS, ICE,  
SNOW, SAND, ETC.

CRUCIALLY, ENERGY OUT **ALSO** INCLUDES RADIATION  
GIVEN OFF BY THE EARTH ITSELF.

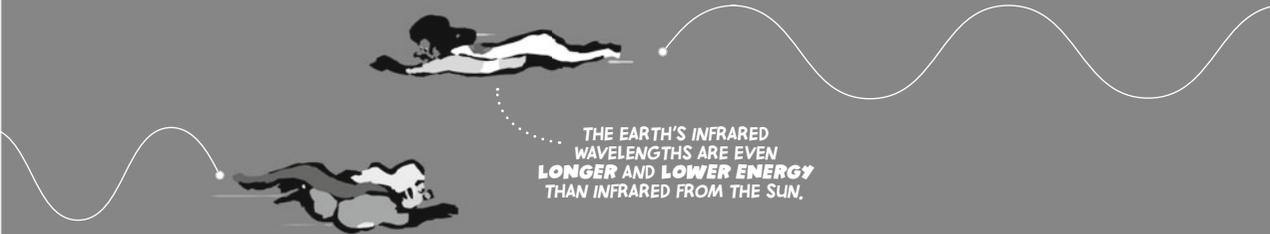
THE EARTH DOESN'T  
EMIT AS MUCH ENERGY  
AS THE SUN...

... BUT IT DOES  
EMIT ENERGY.



THIS OUTGOING ENERGY IS IN THE **INFRARED** PART OF  
THE ELECTROMAGNETIC SPECTRUM...

THE EARTH'S INFRARED  
WAVELENGTHS ARE EVEN  
**LONGER** AND **LOWER ENERGY**  
THAN INFRARED FROM THE SUN.



... AND IS FAMILIAR TO ANYBODY WHO HAS USED **THERMAL IMAGING** EQUIPMENT...

THERE'S A **LEAKY PIPE**  
INSIDE THIS WALL...

... AND A **MAN HIDING**  
IN THAT CLOSET.



... OR HUDDLED NEAR A **HOT FIRE**.

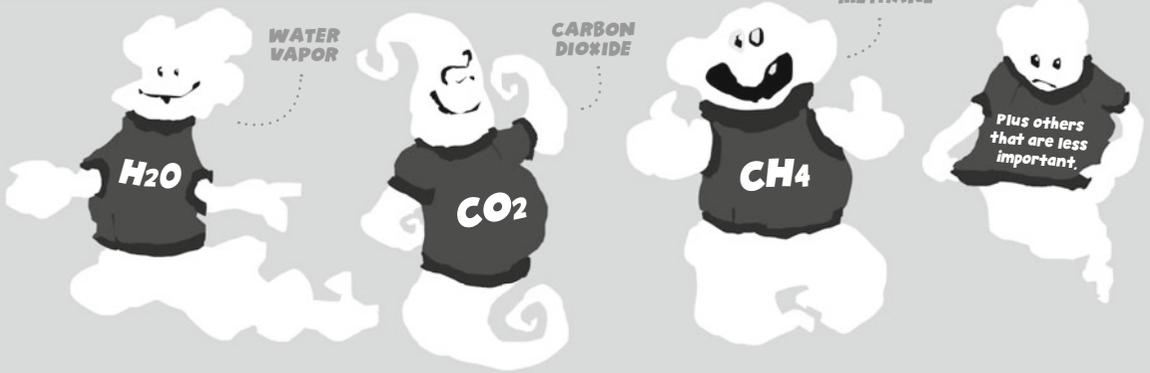
YOU CAN'T **SEE**  
INFRARED LIGHT, BUT  
YOU CAN **FEEL** IT.

IN THE MORNING  
IT WILL NO LONGER  
BE **RED HOT**...

... BUT IT WILL STILL BE  
**INFRARED HOT**.

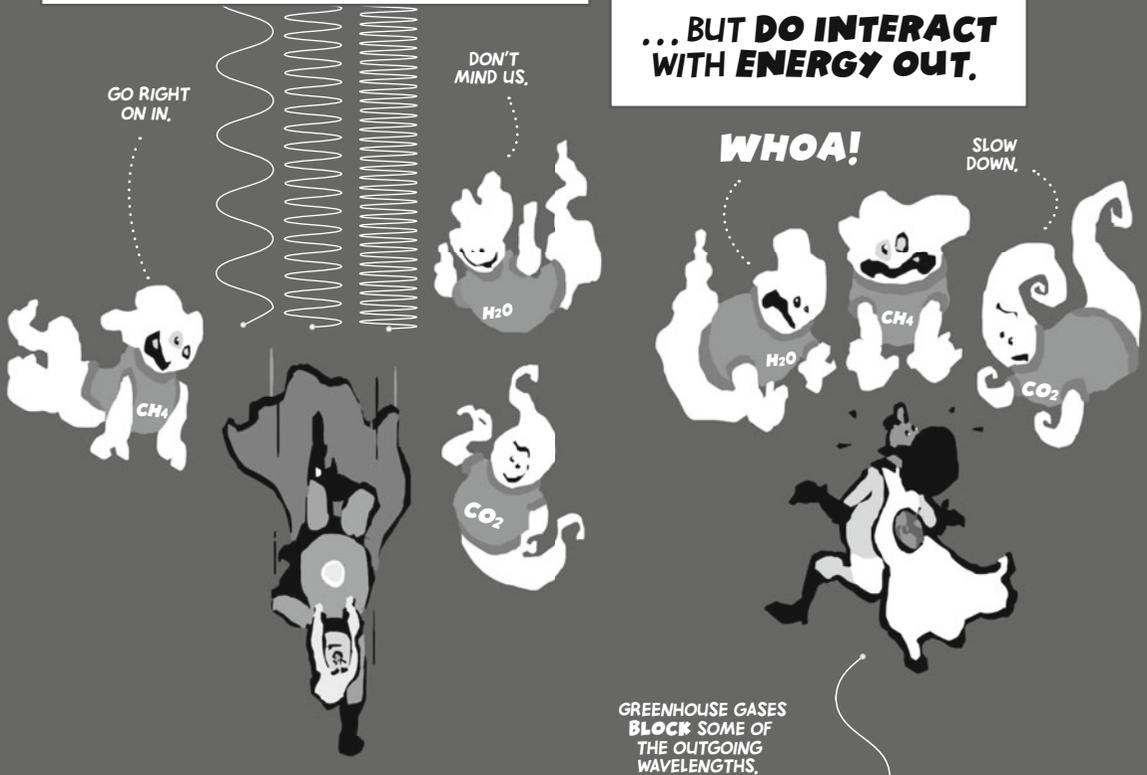


AND THAT BRINGS US TO **GREENHOUSE GASES.**



WHAT MAKES THEM **GREENHOUSE GASES** IS THAT THEY **DON'T INTERACT** MUCH WITH **ENERGY IN...**

... **BUT DO INTERACT** WITH **ENERGY OUT.**



BY REDUCING ENERGY OUT,  
GREENHOUSE GASES **WARM THE PLANET.**

REDUCING ENERGY  
OUT IS ALSO HOW  
**INSULATION** WARMS  
UP YOUR **HOUSE...**

... OR A **BLANKET**  
WARMS UP YOUR **BODY...**

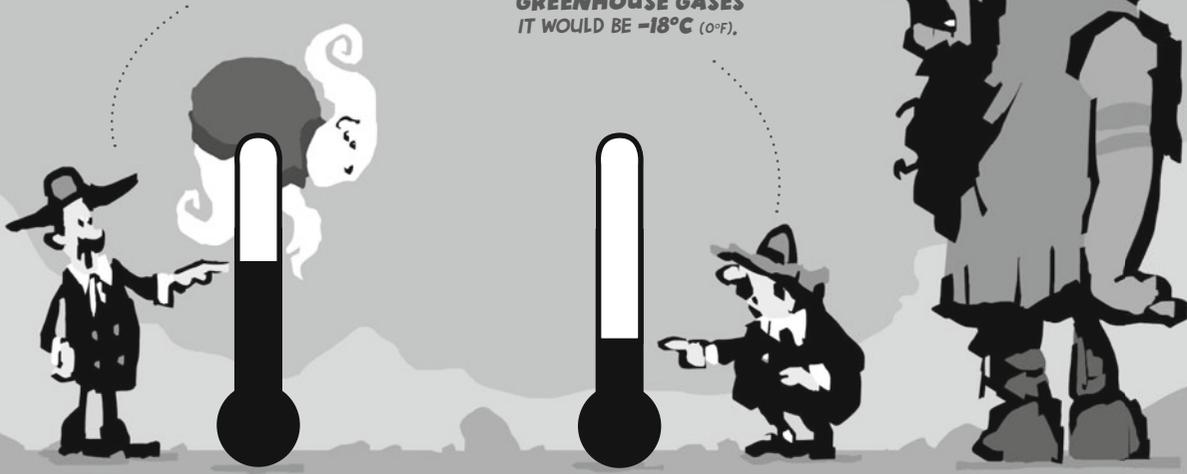
... OR A  
**GREENHOUSE**  
WARMS UP YOUR  
**TOMATOES.**



BY THE 1800s, SCIENTISTS HAD FIGURED OUT THAT GREENHOUSE GASES HAVE A **MAJOR IMPACT** ON THE EARTH'S TEMPERATURE...

THE **ACTUAL** GLOBAL AVERAGE TEMPERATURE IS ABOUT **14°C (57°F)**...

...BUT **WITHOUT GREENHOUSE GASES** IT WOULD BE **-18°C (0°F)**.



...AND TODAY, SCIENTISTS KNOW THAT SIMILAR GREENHOUSE EFFECTS EXIST **ON OTHER PLANETS, LIKE VENUS.**



VENUS HAS **70 TIMES** MORE ATMOSPHERIC CO<sub>2</sub> THAN EARTH.

THAT'S A BIG REASON THE SURFACE TEMPERATURE IS **462°C (863°F)**.

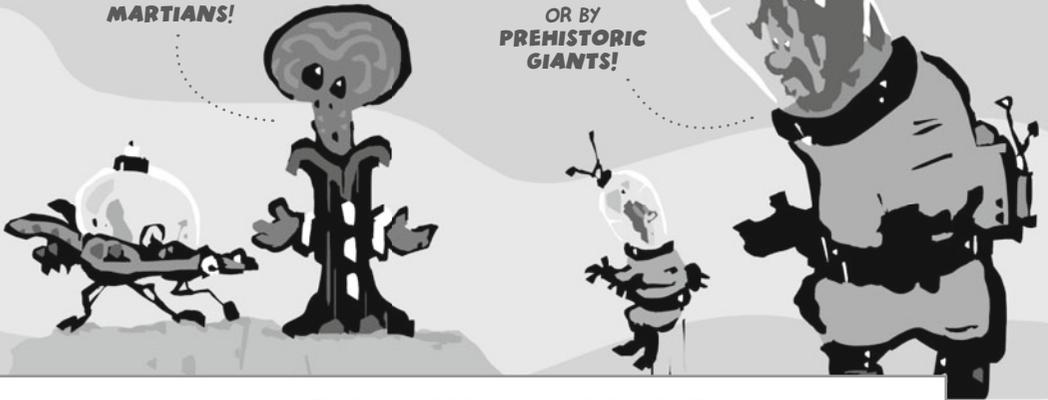
**HOTTER THAN A PIZZA OVEN!**



THE GREENHOUSE EFFECT ON **VENUS** IS OF COURSE **NOT CAUSED BY HUMANS...**

OR BY **MARTIANS!**

OR BY **PREHISTORIC GIANTS!**

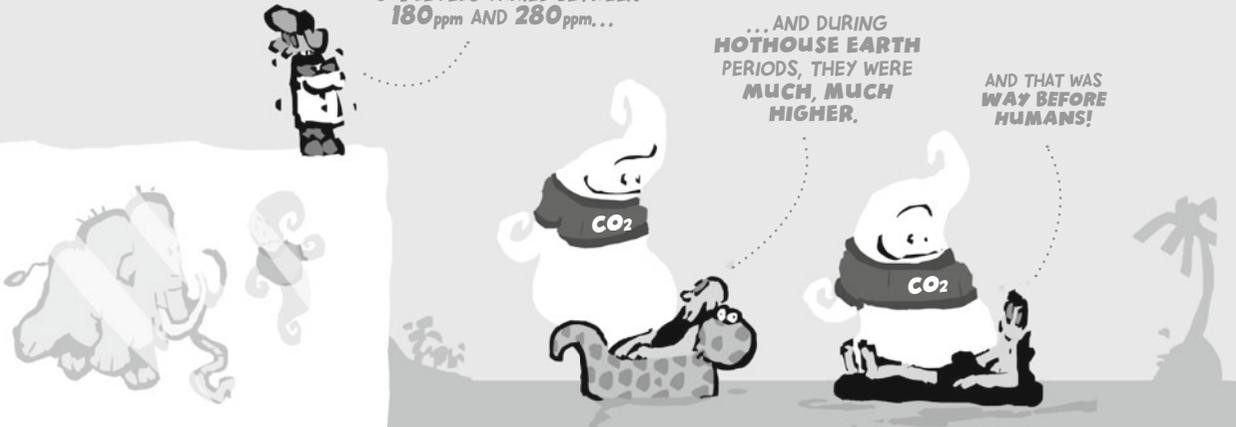


... AND WE DIDN'T CREATE THE **NATURAL GREENHOUSE EFFECT** ON EARTH EITHER.

DURING THE PAST 2 MILLION YEARS  
CO<sub>2</sub> LEVELS VARIED BETWEEN  
180 ppm AND 280 ppm...

... AND DURING  
**HOTHOUSE EARTH**  
PERIODS, THEY WERE  
**MUCH, MUCH**  
**HIGHER.**

AND THAT WAS  
**WAY BEFORE**  
**HUMANS!**

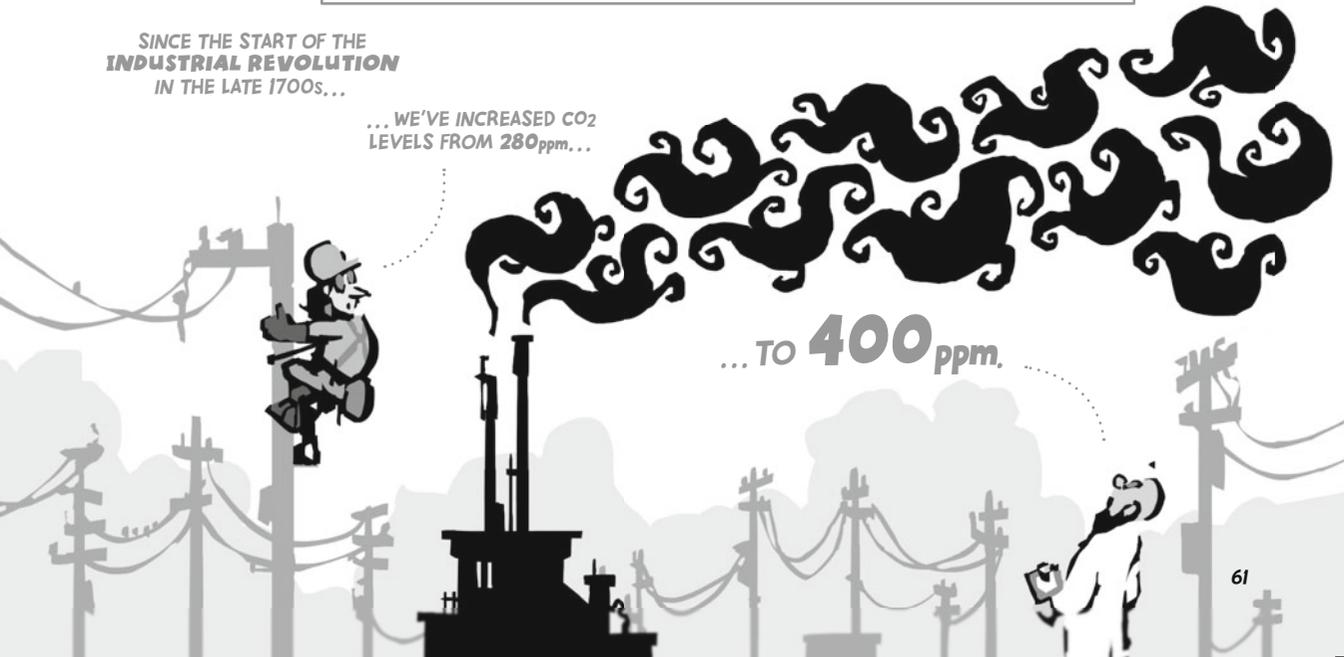


AS WE LEARNED IN CHAPTER 4, HOWEVER, WE'VE BEEN  
**ADDING LOTS** OF GREENHOUSE GASES TO THE ATMOSPHERE.

SINCE THE START OF THE  
**INDUSTRIAL REVOLUTION**  
IN THE LATE 1700S...

... WE'VE INCREASED CO<sub>2</sub>  
LEVELS FROM 280 ppm...

... TO **400** ppm.



THE SWEDISH CHEMIST **ARRHENIUS** WAS ONE OF THE FIRST PEOPLE TO SPECULATE ABOUT THE CONSEQUENCES OF AN **ENHANCED GREENHOUSE EFFECT**.

THIS IS GOING TO BE GREAT FOR **FARMERS** IN SWEDEN!

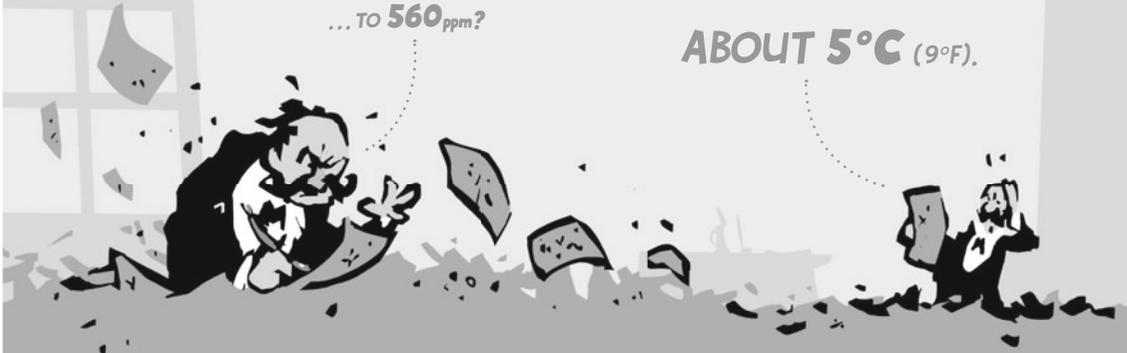


IN 1896 HE STUDIED WHAT WOULD HAPPEN IF WE **DOUBLED** CO<sub>2</sub> CONCENTRATIONS...

...AND MADE A ROUGH CALCULATION OF THE **EVENTUAL INCREASE IN GLOBAL AVERAGE TEMPERATURE**.

WHAT IF WE WENT FROM 280 ppm...  
... TO 560 ppm?

ABOUT 5°C (9°F).



INCREDIBLY, HE CAME **VERY CLOSE** TO THE RANGE THAT CLIMATE SCIENTISTS CALCULATE TODAY.

ABOUT 1.5–4.5°C (2.7–8.1°F).



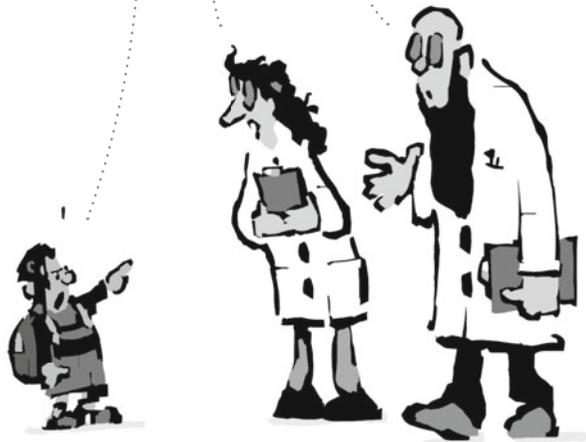
# CHAPTER 6

## CLIMATE SCIENCE

WHY SHOULD  
I TRUST YOU?

DON'T TRUST **US.**

TRUST THE  
**SCIENTIFIC  
METHOD.**



THE **SCIENTIFIC METHOD** INVOLVES  
DEVELOPING **HYPOTHESES...**

**FORCE** EQUALS  
**MASS** TIMES  
**ACCELERATION,**

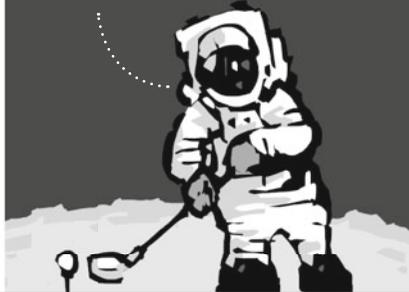


... **TESTING THEM AGAINST THE REAL WORLD...**

YUP, IT WORKS  
ON **EARTH.**



AND ON  
THE **MOON!**



AND ON  
**MARS!**



... AND THEN **REFINING** THOSE **HYPOTHESES** TO **INCORPORATE NEW DATA...**

OOPS, IT DOESN'T  
WORK PERFECTLY  
AT **VERY SMALL**  
**SCALES...**



... OR AT  
**VERY HIGH**  
**SPEEDS.**



... AND **NEW IDEAS.**

LET'S TRY  
SOMETHING  
**DIFFERENT.**



BECAUSE THIS PROCESS INVOLVES  
AN **ENDLESS SUPPLY OF NEW  
QUESTIONS...**

MOMMY, WHERE DO  
**ATOMS** COME FROM?

MOMMY, HOW OLD IS  
THE **UNIVERSE**?

MOMMY, WHY DO  
PRAYING MANTISES EAT  
THEIR HUSBANDS?



...AND **NEW EXPERIMENTS...**

LET'S SEE WHAT  
HAPPENS WHEN WE ADD  
**FROOT LOOPS!**



...IT WILL **NEVER** PRODUCE "**ABSOLUTE TRUTH.**"

EVEN THE  
**THEORY OF GRAVITY**  
IS JUST A **THEORY.**



**BUT THE SCIENTIFIC METHOD IS STILL OUR BEST TOOL FOR  
UNDERSTANDING THE WAY THE WORLD WORKS.**

IT'S WHAT YOU  
SHOULD **LOOK AT**  
BEFORE YOU **LEAP.**



THE IDEAL WAY TO **TEST A HYPOTHESIS**  
IS WITH A **CONTROLLED EXPERIMENT...**

WE GAVE **LOTS OF WATER** TO THESE PLANTS...

...AND **NO WATER** TO THESE ONES,

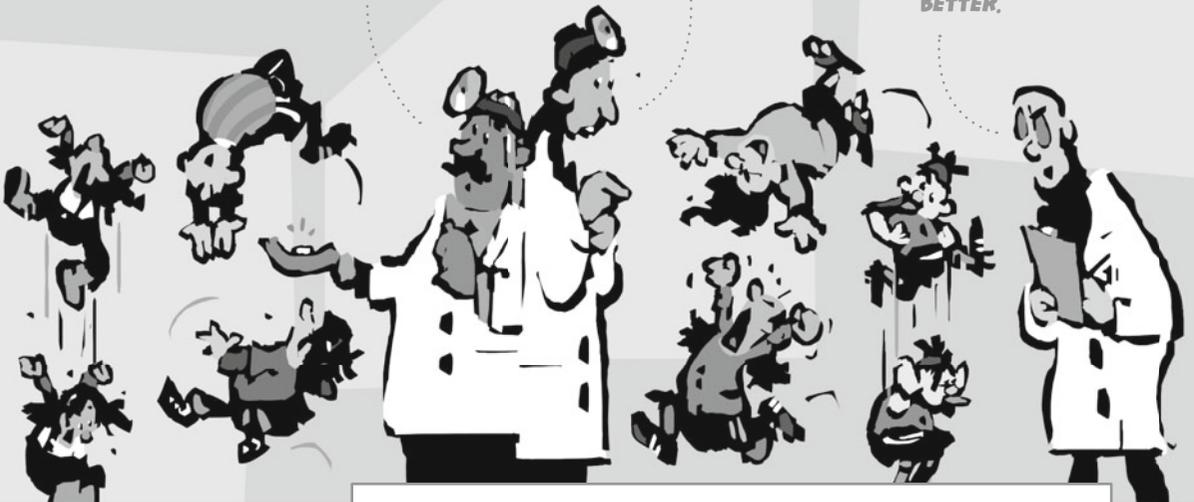
LET'S SEE **WHICH ONES SURVIVE,**



WE GAVE **CHILLA\*ITROL** TO THESE HYPERACTIVE KIDS...

...AND **NOT** TO THESE ONES,

LET'S SEE WHICH ONES CAN **CONCENTRATE BETTER.**



... BUT THAT'S **NOT ALWAYS POSSIBLE.**

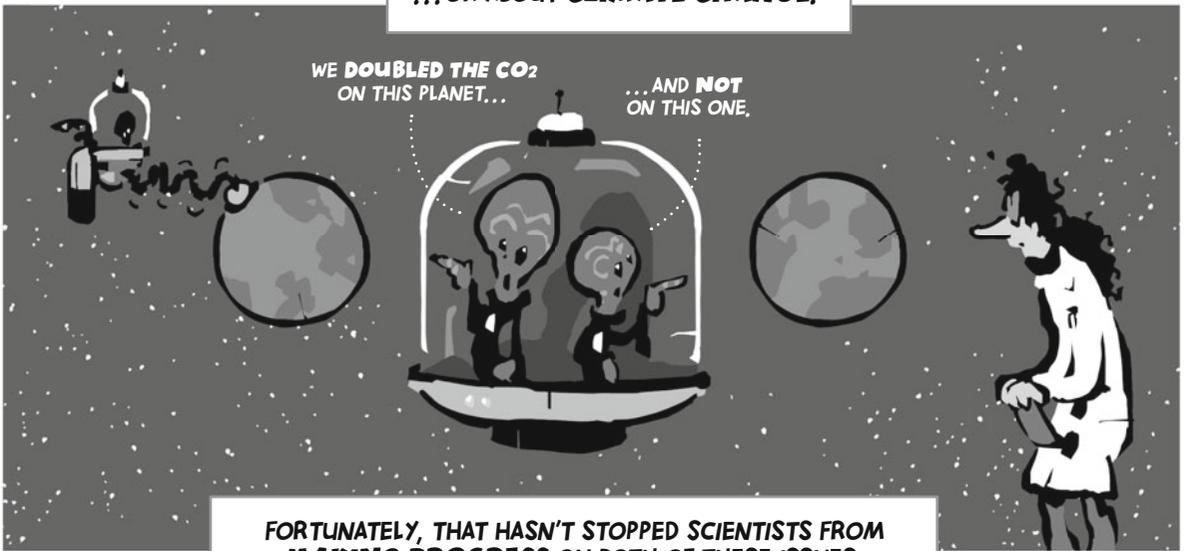
FOR EXAMPLE, YOU CAN'T DO **CONTROLLED EXPERIMENTS** ABOUT **SMOKING...**

WE GAVE **ADDICTIVE NICOTINE STICKS** TO THESE KIDS...  
...AND **NOT** TO THESE ONES.



...OR ABOUT **CLIMATE CHANGE.**

WE **DOUBLED THE CO<sub>2</sub>** ON THIS PLANET...  
...AND **NOT** ON THIS ONE.



FORTUNATELY, THAT HASN'T STOPPED SCIENTISTS FROM **MAKING PROGRESS** ON BOTH OF THESE ISSUES.

WHEN YOU CAN'T WORK IN THE LAB...

... YOU HAVE TO GO OUTSIDE AND **SEARCH FOR CLUES**, LIKE A **DETECTIVE**.



**IN FACT, THE SCIENTIFIC HISTORIES OF SMOKING AND CLIMATE CHANGE ARE SIMILAR.**

WHAT  
**SIMILARITIES**  
COULD THERE  
POSSIBLY BE?



**OVER TIME, THE LINK BETWEEN SMOKING AND DISEASE HAS GROWN CLEARER...**

"THE WEIGHT OF THE EVIDENCE SUGGESTS THAT EXCESSIVE SMOKING IS ONE OF THE CAUSATIVE FACTORS IN LUNG CANCER."



**...AND CLEARER...**

"CIGARETTE SMOKING IS CAUSALLY RELATED TO LUNG CANCER IN MEN."



**...AND CLEARER...**

"CERVICAL CANCER, KIDNEY CANCER, PANCREATIC CANCER..."



**THE ULTIMATE TEST OF A THEORY IS ITS ABILITY TO PREDICT THE FUTURE...**

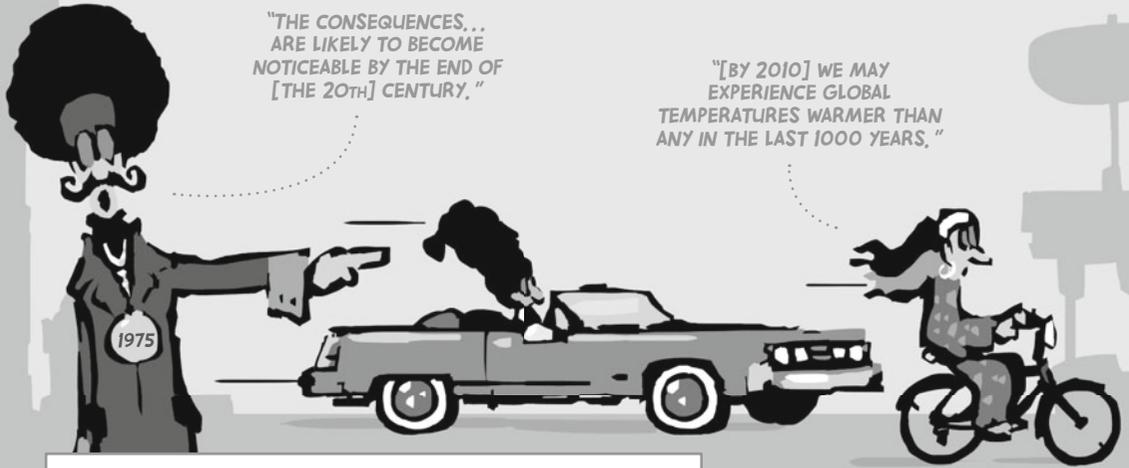
AS ANTICIPATED, SMOKING CAUSED OVER 400,000 DEATHS LAST YEAR IN THE UNITED STATES.



**... AND SOME OF THE BEST EVIDENCE ABOUT CLIMATE CHANGE COMES FROM SUCCESSFUL PREDICTIONS FROM DECADES PAST.**

"THE CONSEQUENCES... ARE LIKELY TO BECOME NOTICEABLE BY THE END OF [THE 20<sup>TH</sup>] CENTURY."

"[BY 2010] WE MAY EXPERIENCE GLOBAL TEMPERATURES WARMER THAN ANY IN THE LAST 1000 YEARS."



**SINCE THE 1970s TEMPERATURES HAVE INCREASED ABOUT 0.15°C (0.3°F) PER DECADE,**

WE PREDICTED 0.2°C (0.4°F).

NOT BAD!

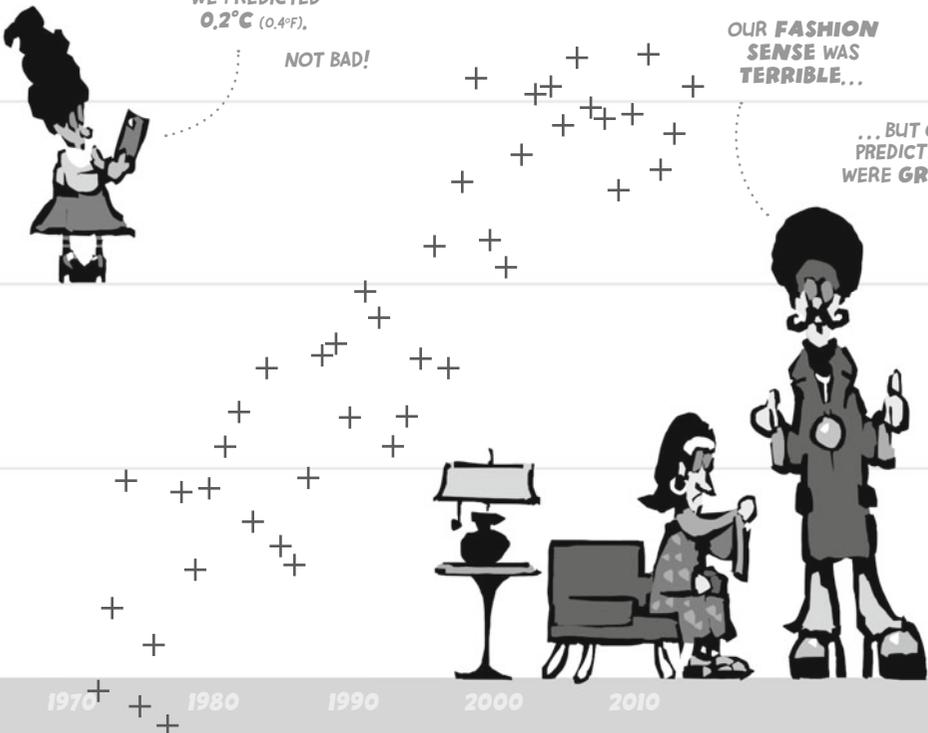
OUR FASHION SENSE WAS TERRIBLE...

... BUT OUR PREDICTIONS WERE GREAT.

+0.6°C

+0.4°C

+0.2°C



Temperatures relative to 20<sup>th</sup> century average.

Source: National Climatic Data Center, <http://www.ncdc.noaa.gov/cag>

AND CLIMATE SCIENTISTS HAVEN'T JUST BEEN  
**RIGHT ABOUT THE BIG PICTURE...**



... THEY'VE ALSO BEEN **RIGHT ABOUT LOTS OF THE DETAILS.**

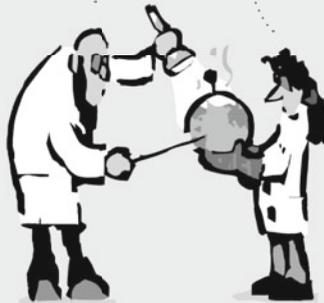
MORE WARMING  
ON **LAND** THAN IN  
THE **OCEANS**?

YUP.



MORE WARMING  
NEAR THE **POLES**  
THAN NEAR THE  
**EQUATOR**?

YUP.



**LESS ENERGY**  
ESCAPING INTO  
**SPACE**?

YUP.

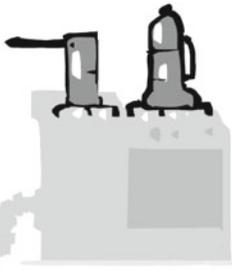


THOSE DETAILS ARE LIKE **FINGERPRINTS** AT A **CRIME SCENE.**

THIS HAS GOT  
**ANTHROPOGENIC**  
**GLOBAL WARMING**  
WRITTEN ALL OVER IT.



LIKE WE SAID, CLIMATE SCIENCE IS LIKE  
**DETECTIVE WORK...**



WHOEVER DID THIS MUST HAVE  
HAD THE **MEANS**, THE **MOTIVE**,  
AND THE **OPPORTUNITY**.



IT WASN'T ME,  
IT WAS **QUEEN  
VICTORIA**.



...AND 100 YEARS OF SCIENTIFIC DETECTIVE WORK...



... HAS CONVINCED THE VAST MAJORITY OF SCIENTISTS  
THAT **HUMAN ACTIVITY IS THE DOMINANT CAUSE OF GLOBAL WARMING.**



WE'RE  
CONVINCED.



WE'RE  
NOT.



**IPCC** = INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE; **AAAS** = AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE; **AMS** = AMERICAN METEOROLOGICAL SOCIETY;  
**ACS** = AMERICAN CHEMICAL SOCIETY; **ASA** = AMERICAN STATISTICAL ASSOCIATION; **NATIONAL ACADEMIES** INCLUDES THE NATIONAL ACADEMIES OF THE U.S., BRAZIL, CANADA, CHINA, FRANCE, GERMANY, INDIA, ITALY, JAPAN,  
RUSSIA, THE U.K., AUSTRALIA, BELGIUM, THE CARIBBEAN, INDONESIA, IRELAND, MALAYSIA, NEW ZEALAND, AND SWEDEN; **NIPCC** = NONGOVERNMENTAL INTERNATIONAL PANEL ON CLIMATE CHANGE

OF COURSE, IT'S ALWAYS POSSIBLE THAT ALL THOSE SCIENTISTS ARE **WRONG**.

WHOOPS, **GLOBAL WARMING** IS ACTUALLY CAUSED BY **BROCCOLI**...

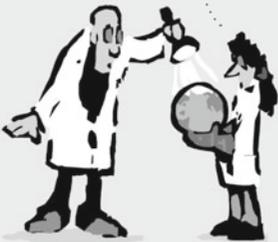
...AND SO IS **LUNG CANCER**...

...AND THE **KILLER** REALLY WAS **QUEEN VICTORIA!**

BUT SO FAR **NOBODY** HAS BEEN ABLE TO IDENTIFY A **GOOD COMPETING THEORY** FOR GLOBAL WARMING...

IS IT **SUNSPOTS?**

NOPE.



**EL NIÑO?**

NOPE.



**MILANKOVITCH CYCLES?**

NOPE.



**BROCCOLI?**

WHA?



...AND THE CASE FOR **ANTHROPOGENIC CLIMATE CHANGE** HAS GOTTEN **STRONGER AND STRONGER**.

IT'S ALL COMING TOGETHER.



**MOST GLOBAL WARMING DATA IS PAINSTAKINGLY GATHERED WITH FANCY EQUIPMENT...**

LIKE  
SATELLITES...



...OCEAN  
BUOYS...



...AND ICE CORE  
DRILLS.



**... BUT IT'S POSSIBLE TO FIND EVIDENCE ALL AROUND US.**

SNOW IS  
MELTING  
EARLIER.



FLOWERS ARE  
BLOOMING  
EARLIER.



BIRDS ARE  
MIGRATING  
EARLIER.



**YOU MIGHT EVEN FIND THIS SORT OF PHENOLOGICAL EVIDENCE IN YOUR OWN BACKYARD.**

**A PIED FLYCATCHER,  
AND IT'S ONLY APRIL 10!**



SOME BIRDS HAVE  
A NATURAL INSTINCT  
TO MIGRATE...



... AND SOME HUMANS  
HAVE A NATURAL INSTINCT  
TO KEEP RECORDS.

THESE DAYS, EVERYTHING WE KNOW ABOUT CLIMATE CHANGE IS INCORPORATED INTO **CLIMATE MODELS RUN BY SUPERCOMPUTERS.**

THESE MODELS DO A PRETTY GOOD JOB OF SIMULATING EVERYTHING FROM THE **ICE AGES...**

... TO **VOLCANIC ERUPTIONS...**

CHECK OUT CHAPTER 3.

**SHORT-TERM COOLING** FOR A FEW YEARS, BUT **NO LONG-TERM IMPACT.**

... AND THEY GIVE US THE BEST INDICATION OF WHAT TO EXPECT **IN THE DECADES AHEAD.**

# **PART TWO**

**PREDICTIONS**





# CHAPTER 7

## GLOBAL WARMING

IS IT JUST ME...

...OR IS IT GETTING  
**HOT IN HERE?!**



NOW THAT WE'VE COVERED THE  
**BASIC SCIENCE OF CLIMATE CHANGE...**

... LET'S TAKE A LOOK AT  
**WHAT MIGHT HAPPEN.**



OF COURSE, LOTS OF THINGS **COULD** HAPPEN  
IN THIS CENTURY AND BEYOND.

WE COULD  
DEVELOP **COLD  
FUSION...**

...OR **FLYING  
WINDMILLS...**

...OR **CARBON-EATING  
TREES...**

...OR **PERPETUAL  
MOTION MACHINES!**

ACTUALLY, THAT ONE  
**COULDN'T HAPPEN;**  
IT'S IMPOSSIBLE.



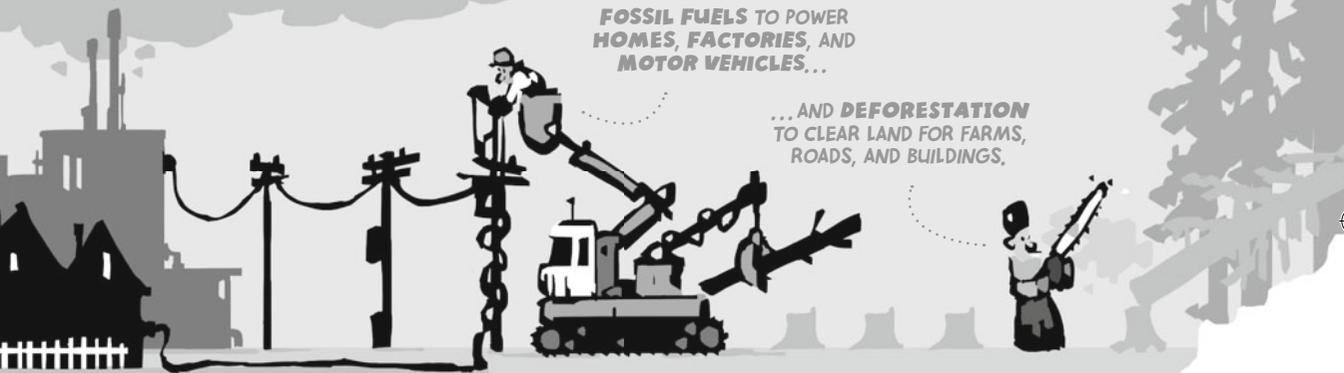
ONE **VERY UNLIKELY** POSSIBILITY IS THAT HUMAN CARBON EMISSIONS WILL STOP **COLD TURKEY**.



THAT'S IT,  
PARTY'S  
OVER.

SHUT **EVERYTHING**  
DOWN **RIGHT NOW**.

A **MUCH MORE LIKELY** POSSIBILITY IS THAT **DEVELOPING COUNTRIES** LIKE CHINA AND INDIA WILL FOLLOW THE PATH BLAZED BY **DEVELOPED COUNTRIES** LIKE THE U.S.



FOSSIL FUELS TO POWER  
HOMES, FACTORIES, AND  
MOTOR VEHICLES...

...AND **DEFORESTATION**  
TO CLEAR LAND FOR FARMS,  
ROADS, AND BUILDINGS.

WE CALL THIS PATH **BUSINESS AS USUAL**.

WHAT IF WE **DIDN'T**  
DO **MUCH** TO REDUCE  
CARBON EMISSIONS?

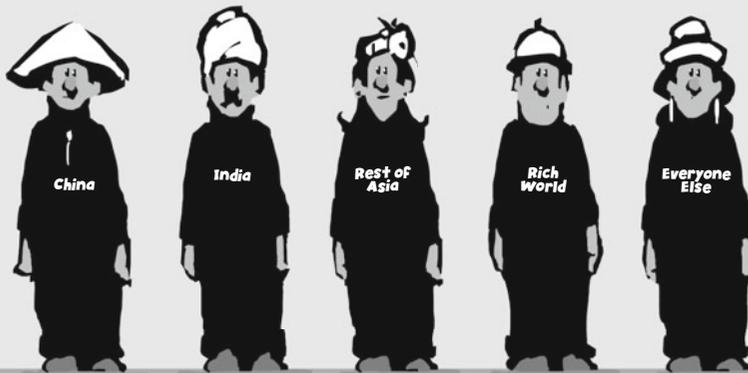
THAT WOULD BE  
**BUSINESS AS**  
USUAL.



THE KEY FACT ABOUT **BUSINESS AS USUAL**  
IS THAT IT WOULD MAKE CO<sub>2</sub> EMISSIONS

**EXPLODE.**

TO SEE WHY, NOTE THAT WE CAN NEATLY DIVIDE THE WORLD'S 7 BILLION PEOPLE INTO  
**5 CHUNKS THE SIZE OF CHINA.**



THEY EACH NEED  
**1.4 BILLION**  
NAPKINS.

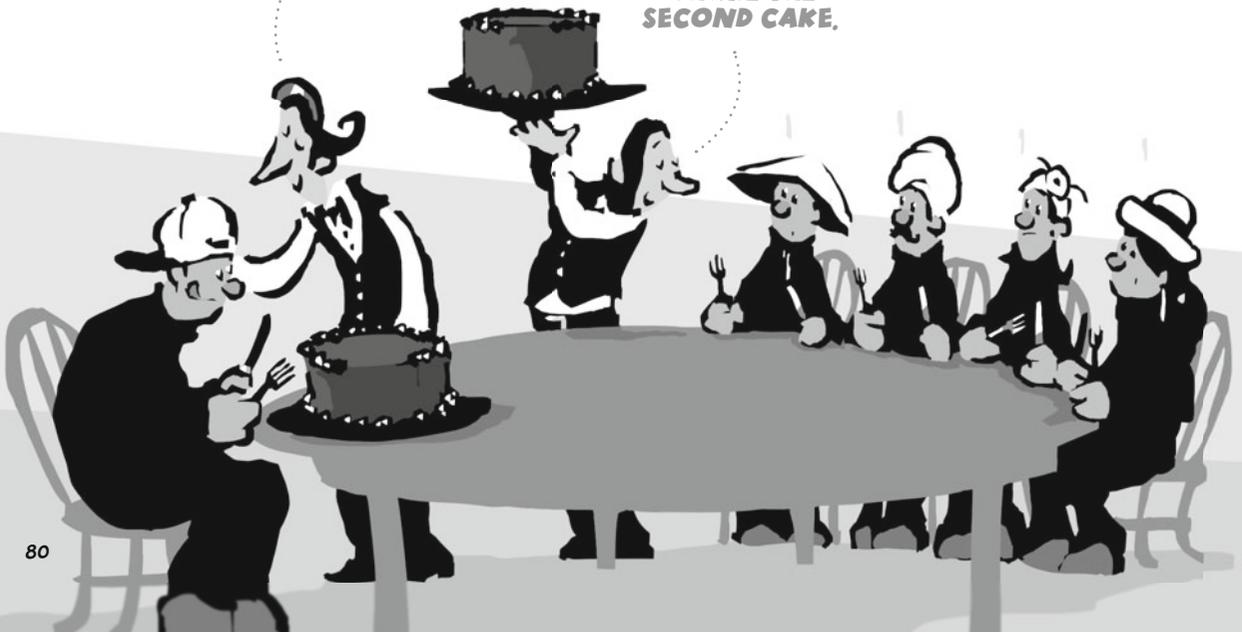


THE RICH WORLD MAKES  
UP **JUST ONE** OF THOSE  
"FIVE CHINAS"...

... BUT AT THE START OF THE 21ST CENTURY  
RICH WORLD ECONOMIES WERE RESPONSIBLE FOR ABOUT  
**HALF OF THE WORLD'S FOSSIL FUEL CONSUMPTION.**

ONE CAKE  
FOR YOU.

YOU ALL CAN  
SHARE THE  
SECOND CAKE.



**UNDER BUSINESS AS USUAL...**



THANKS TO RAPID  
ECONOMIC GROWTH...

... WE CAN  
NOW AFFORD  
MORE CAKE!

... THE OTHER FOUR CHINAS COULD **CATCH UP BY 2100.**

THAT'S **THREE  
MORE CAKES.**

PLUS, POPULATION GROWTH  
COULD **ADD ANOTHER 2 CHINAS  
TO THE PLANET.**



THAT'S ANOTHER  
**TWO CAKES.**

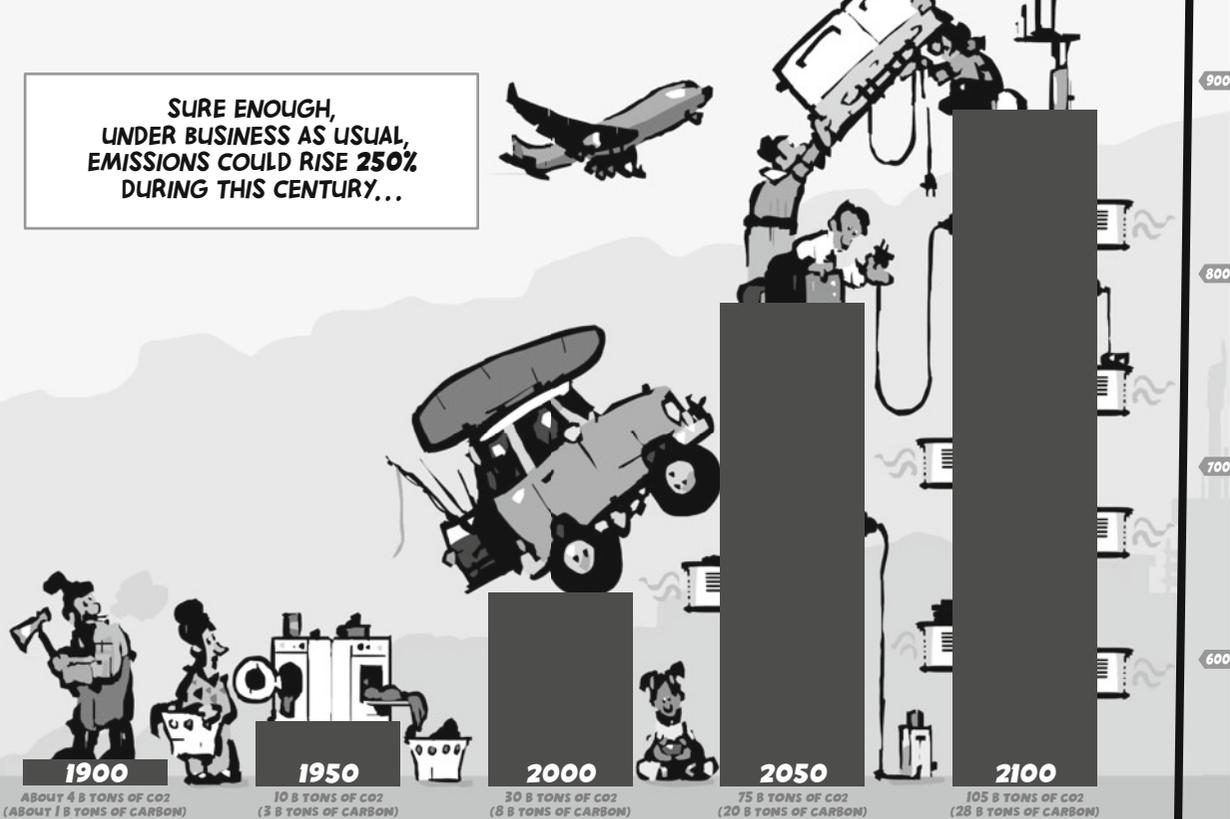
THAT MEANS THAT OVER THE COURSE OF THE CENTURY WE'D  
**INCREASE OUR FOSSIL FUEL CONSUMPTION BY 250%.**

THAT'S LIKE GOING  
FROM 2 CAKES  
A YEAR...

... TO 7.

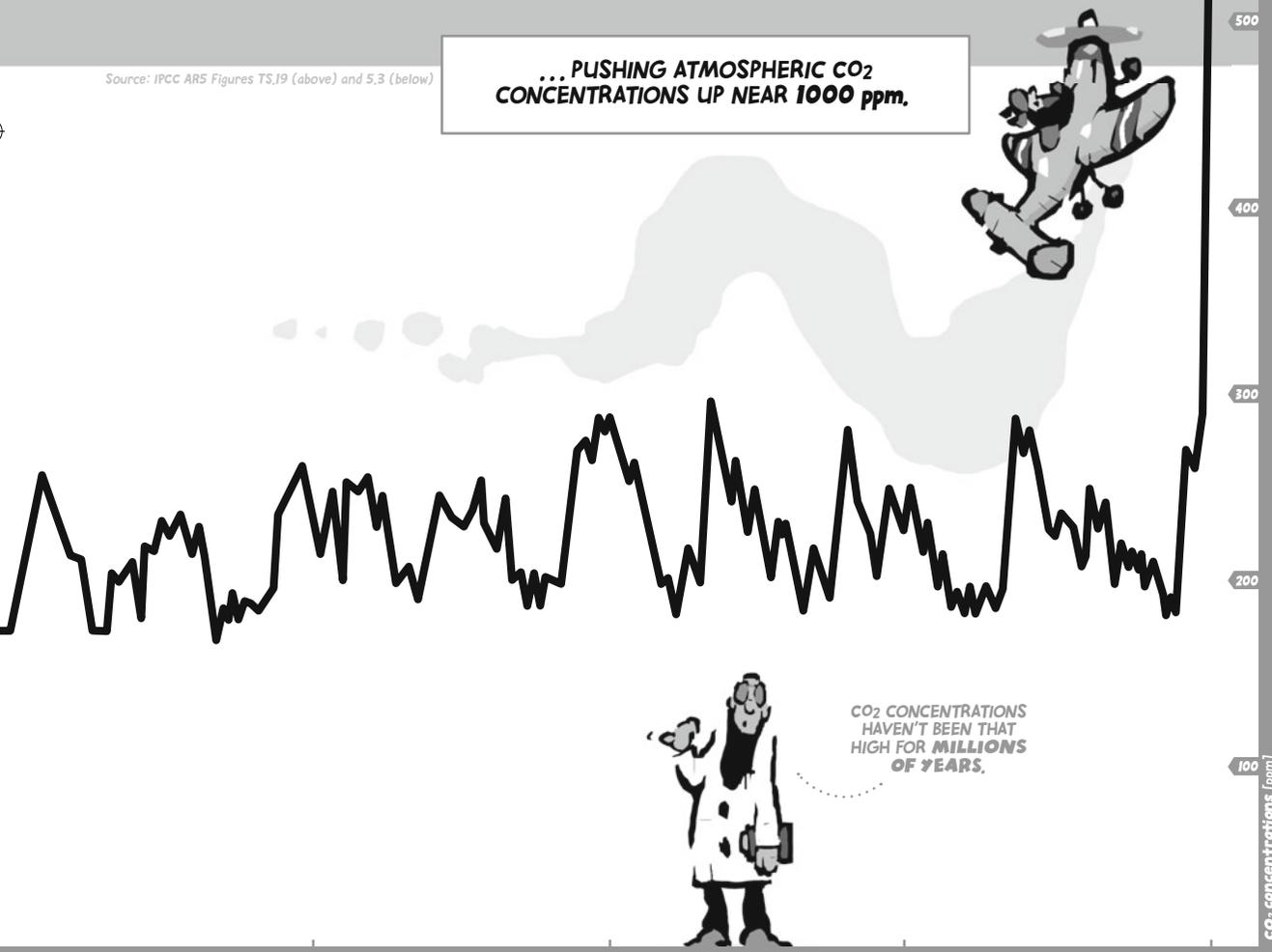


**SURE ENOUGH,  
UNDER BUSINESS AS USUAL,  
EMISSIONS COULD RISE 250%  
DURING THIS CENTURY...**



Source: IPCC AR5 Figures TS.19 (above) and 5.3 (below)

**... PUSHING ATMOSPHERIC CO<sub>2</sub>  
CONCENTRATIONS UP NEAR 1000 ppm.**



**CO<sub>2</sub> CONCENTRATIONS  
HAVEN'T BEEN THAT  
HIGH FOR MILLIONS  
OF YEARS.**

600,000 ya

400,000 ya

200,000 ya

Now

AS A RESULT, THE **GLOBAL AVERAGE TEMPERATURE CHANGE** BETWEEN 2000 AND 2100...

... IF WE DON'T DO MUCH TO REDUCE EMISSIONS...

... WILL LIKELY BE ABOUT **4°C (7°F)**.

THAT ESTIMATE COULD BE A BIT **HIGH**...

... OR MORE THAN A BIT **LOW**...

MAYBE IT'LL BE ONLY **3°C**.

MAYBE AS MUCH AS **5° OR 6°C**.

**MEH.**

WE'LL COME BACK TO **UNCERTAINTY** IN CHAPTER II.

... BUT IT MAKES A GOOD **STARTING POINT** FOR UNDERSTANDING THE CHANGES THAT ARE COMING.

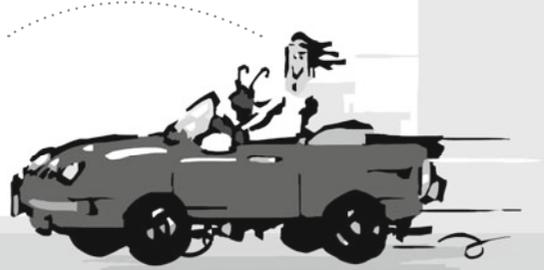
IT'S JUST A **NUMBER**... ... WHAT EXACTLY DOES IT MEAN?

FOR SOME PEOPLE, A GLOBAL INCREASE OF 4°C SOUNDS LIKE **NO BIG DEAL...**

I'LL JUST **PAY A BIT MORE** FOR AIR CONDITIONING IN THE SUMMER...

... AND A **BIT LESS** FOR HEATING IN THE WINTER.

WHY ALL THE **FUSS?**



... WHILE TO OTHERS IT SOUNDS LIKE **A BIG, BIG DEAL.**

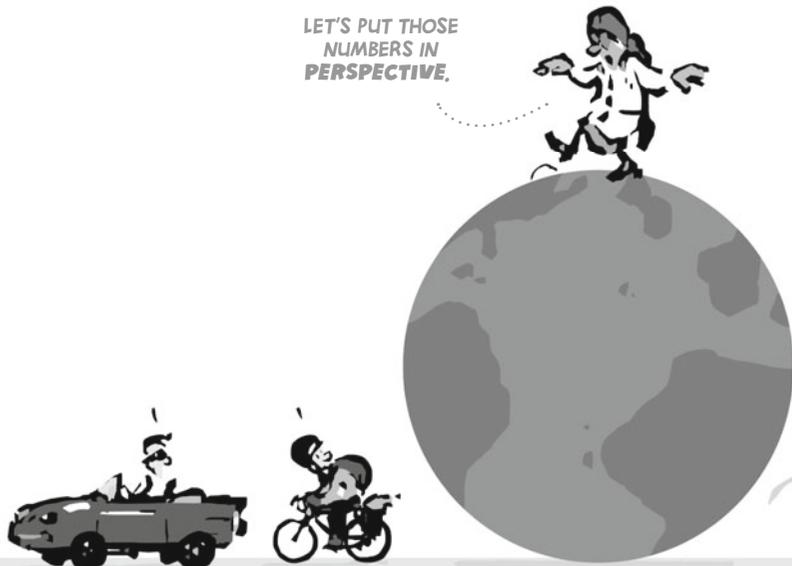
IN MOST PLACES ON EARTH, THE **AVERAGE SUMMER** IN 2100...

... WILL BE **HOTTER THAN THE HOTTEST SUMMER OF THE 20TH CENTURY!**

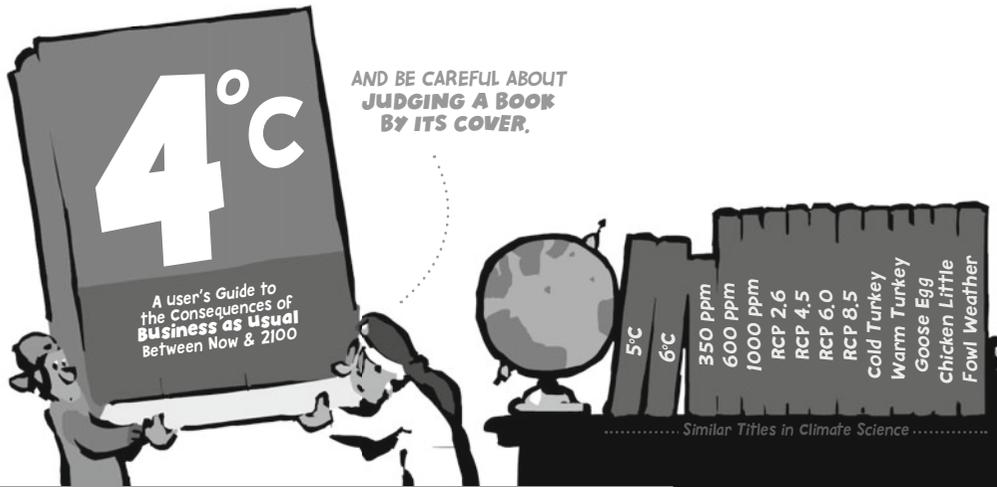


BUT NEITHER OF THESE IS THE **BEST WAY TO THINK ABOUT IT.**

LET'S PUT THOSE NUMBERS IN **PERSPECTIVE.**



**THE BEST WAY TO THINK ABOUT 4°C IS LIKE THE TITLE OF A HUGE BOOK.**



**INSIDE THE BOOK ARE DESCRIPTIONS OF LOTS OF DIFFERENT CHANGES...**

**...IN LOTS OF DIFFERENT PLACES.**

TELL ME ABOUT SEA LEVEL RISE IN ASIA.

ONE CHAPTER A NIGHT AND WE'LL BE DONE BY THE TIME YOU GO TO COLLEGE.



FOR EXAMPLE, A GLOBAL INCREASE OF **4°C (7°F)** WOULD LIKELY WARM **OCEANS** BY ONLY **3°C (5°F)**...

... **LAND AREAS** BY MORE, AROUND **5°C (9°F)**...



OUCH OUCH OUCH OUCH.

... AND THE **ARCTIC** BY A WHOPPING **8°C (15°F)**.

LESS ICE MEANS MORE ABSORPTION OF SOLAR ENERGY.

IT'S THE ICE-ALBEDO EFFECT!



AND THAT'S JUST THE **TIP OF THE ICEBERG.**

welcome to the  
**ARCTIC CIRCLE**



"Well, there **used to be icebergs** here."

THE FACT IS, A GLOBAL INCREASE OF 4°C (7°F) WOULD **TRANSFORM THE ENTIRE WORLD...**

Auf Wiedersehen **FROSTBITE**



Hallo **HEATSTROKE**



Salaam from the **FERTILE FARMLAND** of **BANGLADESH**

"Well, there **used to be farmland** here."



WHEN IT COMES TO **LATITUDE:**

**50**

IS THE **NEW**

**40**



**SMOKEY THE BEAR** KNOWS...



...YOU GET MORE **FOREST FIRES** WHEN IT'S **HOT AND DRY.**

Monsoons just got...

**Monsoonier**



The **World's Deserts** **NOW EVEN BIGGER & DRIER!**



**SIBERIA**

THE NEW **AGRICULTURAL HEARTLAND.**



Swim the **Great Barrier Reef**



**HURRY, offer ENDS SOON!**

... BECAUSE WHEN THE CLIMATE CHANGES, **EVERYTHING CHANGES.**

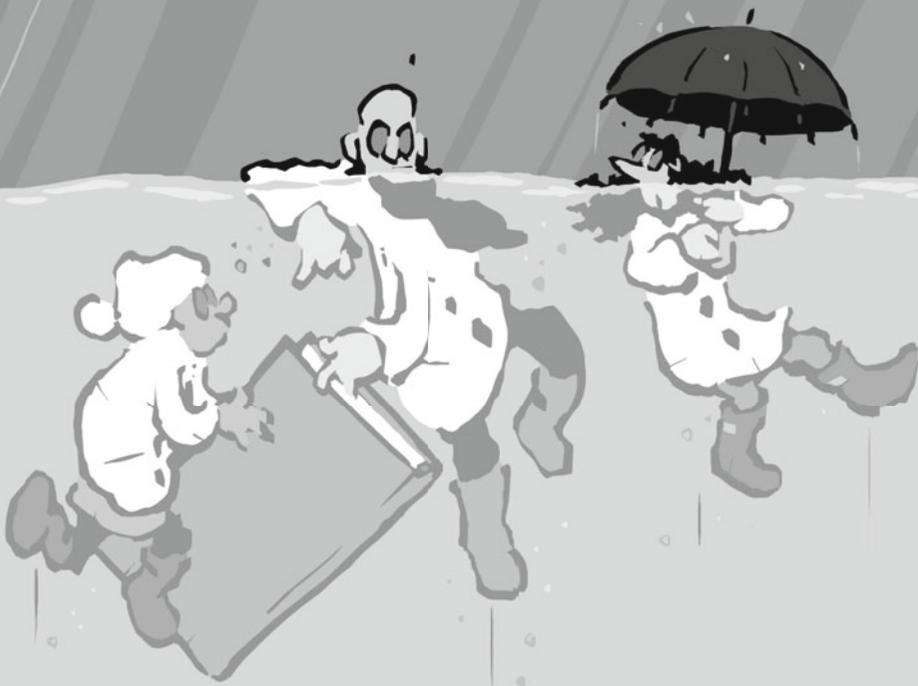
WE'RE GOING TO SPEND THE NEXT TWO CHAPTERS  
LEARNING ABOUT SOME OF THESE CHANGES IN **GREATER DETAIL**.

WE'LL START WITH THE  
CHANGES THAT HAVE  
TO DO WITH **WATER**.



# CHAPTER 8

## WATER



**WATER COVERS MOST OF THE EARTH'S SURFACE...**

**...AND THE WATER CYCLE...**

**WATER CONTINUOUSLY *EVAPORATES* INTO THE ATMOSPHERE...**

**... WHERE IT LINGERS AS CLOUDS AND WATER VAPOR BEFORE *PRECIPITATING* AS RAIN AND SNOW.**

**SOME WATER ACCUMULATES ON LAND AS *SNOW AND ICE* AND IN *LAKEs*...**

**... AND SOME SEEPS *UNDERGROUND*...**

**... BUT *MOST* RETURNS TO *THE OCEANS*.**

97% OF THE EARTH'S WATER IS STORED IN THE OCEANS.

**... IS AS CRUCIAL TO *LIFE ON EARTH* AS THE CARBON CYCLE.**



**Mostly Water and Carbon**



**Mostly Water and Carbon**



**Mostly Water and Carbon**

**YOU ARE WHAT YOU DRINK!**

**WATER AND CLIMATE ARE ALSO CLOSELY RELATED.**

**HUMID AIR AND OCEAN CURRENTS MOVE HEAT FROM THE EQUATOR TOWARD THE POLES,**

**LIKE A COOLING AND HEATING SYSTEM!**



**SO IT'S NOT SURPRISING THAT MANY OF THE MOST IMPORTANT IMPACTS OF CLIMATE CHANGE...**

SEA LEVEL RISE



FLOODS AND DROUGHTS



OCEAN ACIDIFICATION



**... ARE RELATED TO THE THREE FORMS OF WATER,**

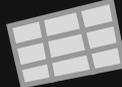
**LIQUID**



**WATER**



**SOLID**



**ICE AND SNOW**



**GAS**



**WATER VAPOR**



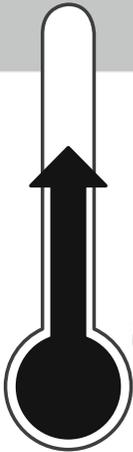


WE BEGIN WITH THE **OCEANS**, WHICH ARE **WARMING UP** JUST LIKE THE REST OF THE PLANET.

OVER 90% OF THE EXTRA ENERGY TRAPPED BY GREENHOUSE GASES **ENDS UP IN THE OCEANS**.



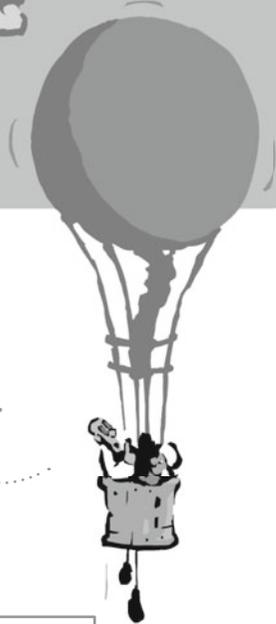
AS WATER HEATS UP, IT **EXPANDS...**



LIKE MERCURY IN A THERMOMETER...



...OR HOT AIR IN A BALLOON.



...AND THE RESULT IS **RIISING SEA LEVELS**.

**THERMAL EXPANSION** ACCOUNTED FOR ABOUT **HALF** OF THE 7 INCHES OF SEA LEVEL RISE WE SAW DURING THE 20<sup>TH</sup> CENTURY.

THE OTHER HALF WAS FROM **MELTING GLACIERS AND ICE SHEETS**.



SEA LEVEL RISE IS LIKELY  
TO **ACCELERATE** IN THE YEARS AHEAD,  
POSING RISKS TO **AGRICULTURE**...

INSTEAD OF WORRYING  
ABOUT **WEEDS**...

...I'M WORRIED ABOUT  
**SEAWEEDS**.

... TO **LOW-LYING CITIES**...

... AND EVEN TO **ENTIRE COUNTRIES**.

Welcome to the  
**Maldive Islands**

"Well, there **used to be** islands here."

ALL TOLD, **BUSINESS AS USUAL** WILL LIKELY LEAD TO ABOUT  
**2 FEET OF SEA LEVEL RISE THIS CENTURY**.

BUT IT COULD BE  
**TWO OR THREE**  
TIMES AS MUCH...

... DEPENDING ON  
WHAT HAPPENS TO **ICE**  
AND **SNOW**.



THE **ICE SHEETS OF GREENLAND AND ANTARCTICA** ARE CRUCIAL TO SEA LEVEL RISE THIS CENTURY.

IF THEY MELT **SLOWLY**, SEA LEVEL RISE WILL BE ABOUT **2 FEET**.



IF THEY MELT **QUICKLY**, IT COULD BE AS MUCH AS **6 FEET**.



IN CONTRAST, **MELTING ICE IN THE ARCTIC DOES NOT RAISE SEA LEVELS BECAUSE IT'S FLOATING...**



WHEN FLOATING ICE MELTS...



...THE WATER LEVEL DOESN'T CHANGE.

YOU CAN WATCH IT HAPPEN IN YOUR DRINK.



... BUT IT DOES MEAN **BIG CHANGES** IN THE ARCTIC ENVIRONMENT.

Welcome Back to the

# ARCTIC CIRCLE

"An emerging **Epicenter of Industry and Trade** akin to the **Mediterranean Sea**."

**GLOBAL WARMING ALSO MEANS A  
SHIFT FROM SNOW TO RAIN...**

THESE **WINTER  
OLYMPICS**  
SURE ARE WEIRD!



MAYBE WE SHOULD  
TRY **WATER SKIING**  
INSTEAD.

... AND **EARLIER MELTING**  
OF THE SNOW THAT DOES FALL,

OF COURSE, **SNOW ISN'T JUST FOR SKIING...**

IT'S ALSO A  
**NATURAL RESERVOIR**  
THAT STORES WATER FROM  
THE **WINTER...**



... AND RELEASES IT IN  
THE **SUMMER.**



... SO LACK OF SNOW COULD MEAN BIG TROUBLE FOR  
**FARMERS, FAMILIES, AND INDUSTRY.**

ESPECIALLY WHEN  
COMBINED WITH **CHANGES**  
IN **RAINFALL...**

... WHICH IS OUR  
NEXT TOPIC.





WE LEARNED IN CHAPTER 5 THAT WATER VAPOR IN THE ATMOSPHERE WORKS AS A **GREENHOUSE GAS** TO **WARM THE PLANET**.

ENERGY IN?

GO RIGHT AHEAD.



ENERGY OUT?

YOU SHALL NOT PASS!



BUT IT TURNS OUT THAT AS THE PLANET WARMS, THE ATMOSPHERE HOLDS **MORE WATER VAPOR**.

THE **CLAUSIUS-CLAPEYRON** RELATIONSHIP...

... SAYS THAT EACH ADDITIONAL 1°C MEANS 7% MORE WATER VAPOR.



HEAT AND HUMIDITY GO HAND IN HAND.



AND THAT CREATES YET ANOTHER **POSITIVE FEEDBACK LOOP**.

**HOT AND HUMID** TURNS INTO **EVEN MORE HOT AND HUMID**.



MORE HUMIDITY MAKES IT HOTTER...



MORE HEAT MAKES IT MORE HUMID...



**GLOBAL WARMING ALSO MEANS BIG CHANGES IN PRECIPITATION.**

IN GENERAL, **DRY** WILL GET **DRIER...**

...AND **WET** WILL GET **WETTER.**



**AS THE PLANET WARMS, THERE WILL BE MORE EVAPORATION FROM THE SURFACE...**

**I'M SWEATY?**

... WHICH MEANS MANY **DRY** PLACES WILL GET **DRIER.**

**I'M THIRSTY?**



**BUT THE EXTRA MOISTURE IN THE ATMOSPHERE WILL ALSO CAUSE MORE INTENSE RAINSTORMS...**

... SO MANY **WET** PLACES WILL GET **WETTER.**

THE WATER CYCLE IS GOING **CRAZY!**

AN ADDITIONAL 4°C MEANS ABOUT 28% MORE WATER VAPOR IN THE ATMOSPHERE.



**BONUS**  
**LIQUID**  
**WATER**

FINALLY, WE RETURN  
TO THE OCEANS.

THEY'RE NOT JUST  
WARMING UP AND  
EXPANDING...

... THEY'RE ALSO  
GETTING MORE  
ACIDIC.



**OCEAN ACIDIFICATION** HAPPENS WHEN  
CO<sub>2</sub> FROM THE ATMOSPHERE **DISSOLVES IN OCEAN WATER...**

RECALL FROM PAGE 47  
THAT OVER 25% OF OUR  
CO<sub>2</sub> EMISSIONS END  
UP **DOWN THERE.**

AND RECALL  
THIS FROM  
CHEMISTRY  
CLASS!



SHOW OFF!



... INCREASING THE CONCENTRATION OF **HYDROGEN IONS** IN THE WATER,

MORE HYDROGEN  
IONS (H<sup>+</sup>)...

... MEANS MORE  
ACIDIC.



**Bleach**  
pH = 12.6

**Sea Water**  
pH = 8

**Coca-Cola**  
pH = 2.52

**INCREASED ACIDITY ERODES  
CORAL REEFS...**

EXTRA HYDROGEN IONS BREAK  
DOWN THE REEF **FASTER**  
THAN THE CORAL CAN  
BUILD IT UP.

... AND **DISSOLVES** THE **SKELETONS** AND **SHELLS** OF  
SEA CREATURES, BOTH **BIG**...

YUCK.

DOUBLE  
YUCK.

... AND **SMALL**.

**COCCOLITHOPHORES**



**PTEROPODS**



**FORAMINIFERA**



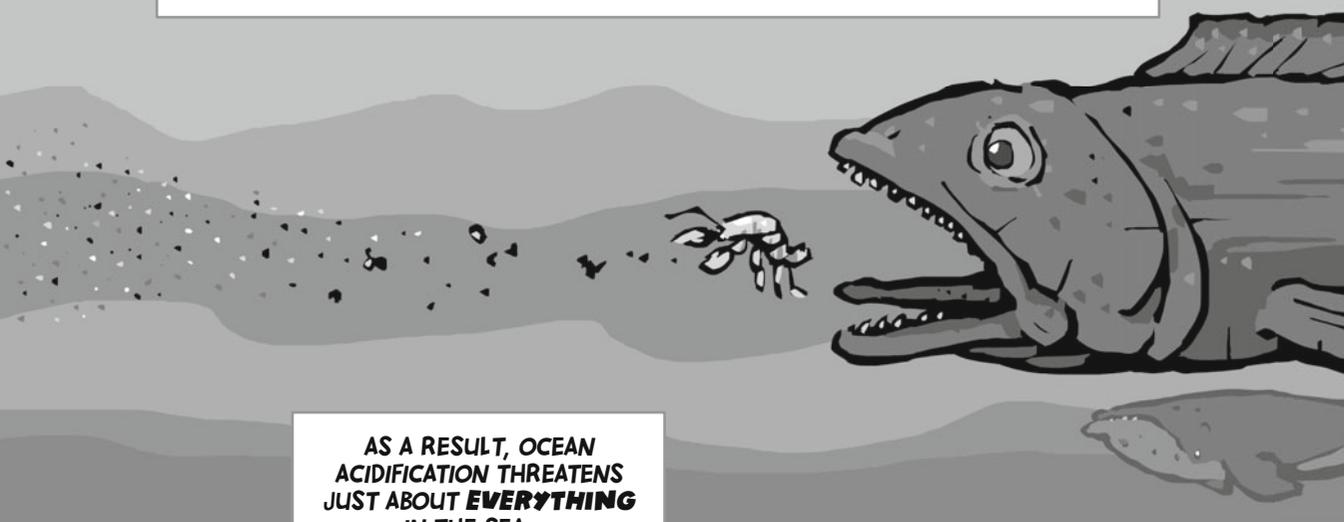
EVEN THOUGH YOU'VE  
**PROBABLY NEVER**  
HEARD OF THEM...

CACALITHOFARTS!  
FORBADIFADALIDA!

PHPHPHTHTHTHBBBB!

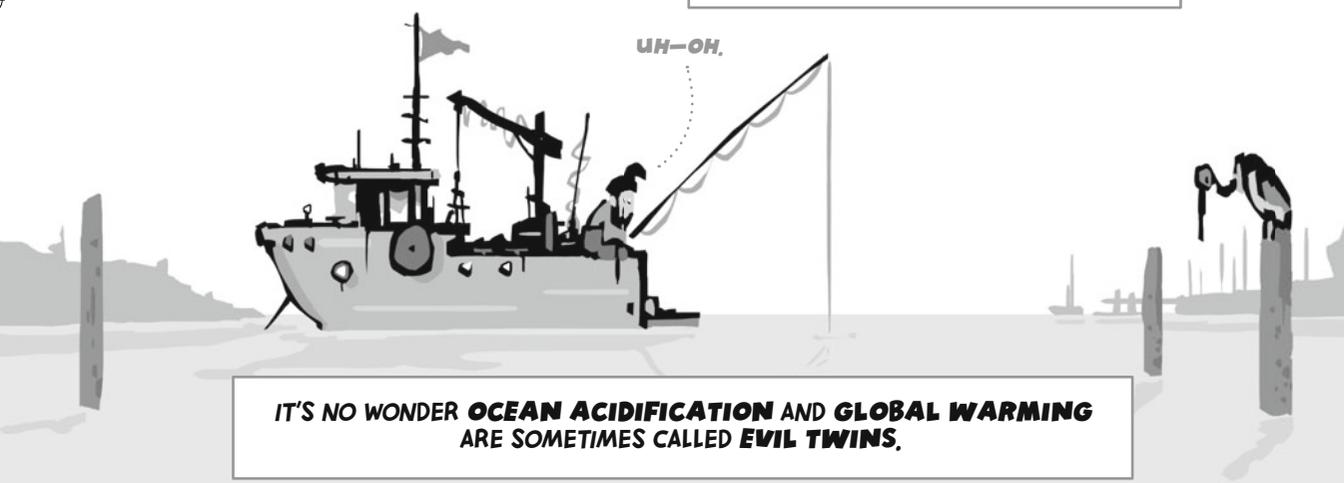


... THOSE TINY SEA CREATURES FORM THE **BASE OF THE MARINE FOOD CHAIN.**



AS A RESULT, OCEAN  
ACIDIFICATION THREATENS  
JUST ABOUT **EVERYTHING**  
IN THE SEA...

... AND **EVERYONE** CONNECTED TO IT.



IT'S NO WONDER **OCEAN ACIDIFICATION** AND **GLOBAL WARMING**  
ARE SOMETIMES CALLED **EVIL TWINS.**

LET'S PUT COCA-COLA IN THE  
BUCKET AND **WATCH THE**  
SHELLFISH DISSOLVE.

WE'RE **DOUBLE**  
TROUBLE!



# CHAPTER 9

## LIFE ON EARTH



WHEN CIRCUMSTANCES CHANGE,  
LIVING THINGS **ADAPT...**



SORRY, NO  
SEAL MEAT  
TODAY.

IN THAT CASE,  
GIVE ME 50  
POUNDS OF THE  
**SNOW GOOSE.**



... AND SPECIES **EVOLVE...**



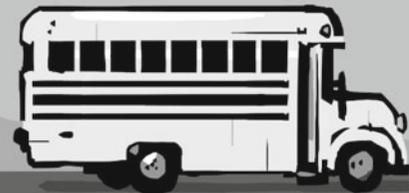
GO BACK **100,000**  
**GENERATIONS** AND YOUR  
ANCESTORS WERE JUST REGULAR  
OLD **BROWN BEARS.**

... AND IF THEY DON'T SUCCEED **IT'S CURTAINS.**

WHAT USE ARE BIG WEBBED FEET  
AND TRANSPARENT FUR IF  
THERE'S **NO MORE ICE?**



THAT'S WHY YOU  
NEED TO GO TO  
**SCHOOL** AND PAY  
**ATTENTION!**

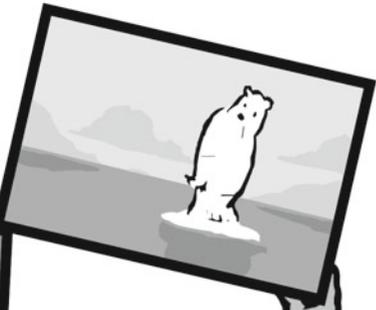


MANY OF THE **CHANGING CIRCUMSTANCES** IN THE WORLD TODAY ARE **CAUSED BY HUMANS...**

BOY IS THAT AN **UNDERSTATEMENT!**



... AND CLIMATE CHANGE IS GOING TO ADD AN **EXTRA CHALLENGE.**

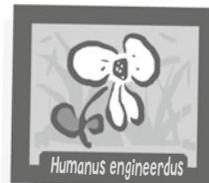
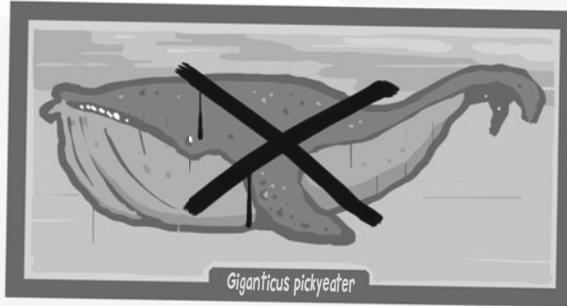
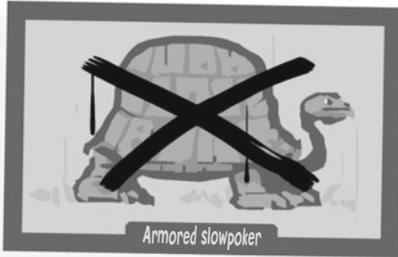


CLIMATE CHANGE IS LIKELY TO BE A BIG PROBLEM FOR SPECIES THAT **EVOLVE SLOWLY**...

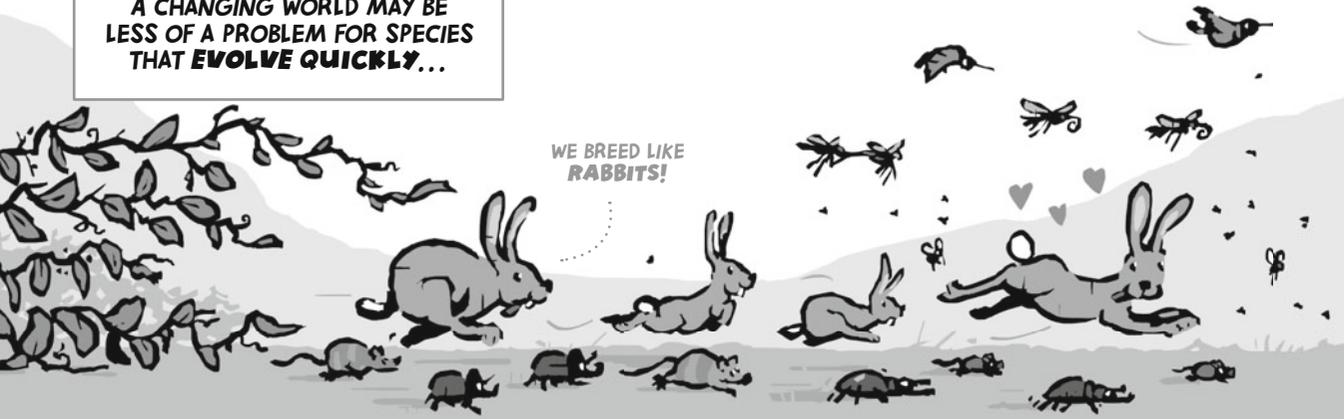
WE TAKE **EVERYTHING SLOWLY**.



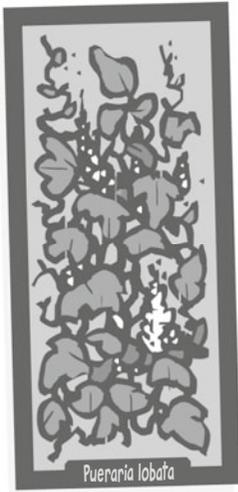
...AND SCIENTISTS ESTIMATE THAT **40–70%** OF ALL THE SPECIES ON EARTH MAY GO **EXTINCT** OVER THE NEXT 100 YEARS.



A CHANGING WORLD MAY BE LESS OF A PROBLEM FOR SPECIES THAT **EVOLVE QUICKLY...**



...OR CAN **ADAPT QUICKLY...**



*Pueraria lobata*



*Rattus norvegicus*



*Columba livia*



*Homo sapiens*

HEY!



...OR MIGHT **BENEFIT** FROM THE NEW REALITY.

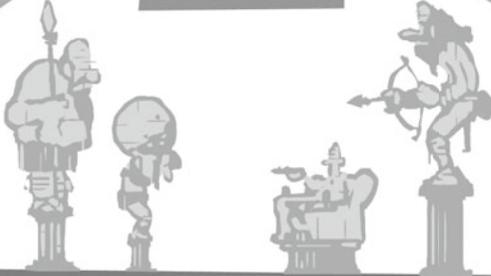


CERTAIN PLANTS DO **BETTER** WITH MORE CO<sub>2</sub>...

...AS LONG AS IT DOESN'T GET **TOO HOT.**

AS FOR HOW CLIMATE CHANGE WILL AFFECT **HUMANS...**

HALL OF MAN  
AND WOMAN!



FINALLY,  
SOMETHING  
I CAN CARE  
ABOUT.

C'MON DAD,  
LET'S  
GO BACK TO THE  
ANIMALS!



... IT'S A BIT **HARD TO SAY**  
BECAUSE WE'RE SO GOOD AT  
**ADAPTING.**

WHAT IF **OCEAN  
ACIDIFICATION** DESTROYS  
MARINE ECOSYSTEMS?



WE'LL JUST EAT  
**FARMED FISH!**



BUT WHAT WOULD  
YOU **FEED** THE  
FARMED FISH?



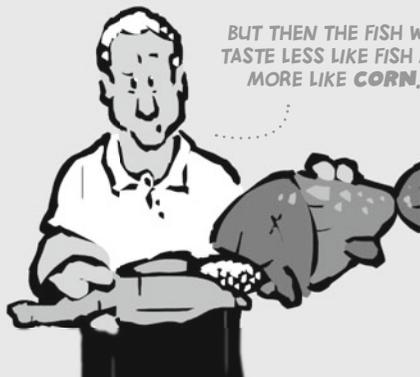
**CORN!**

BUT HOW ARE YOU  
GOING TO **GROW**  
ALL THAT **CORN?**



**GENETIC  
MODIFICATION!**

BUT THEN THE FISH WILL  
TASTE LESS LIKE FISH AND  
MORE LIKE **CORN.**



DON'T WORRY,  
MY **TASTE  
BUDS** WILL  
ADAPT.



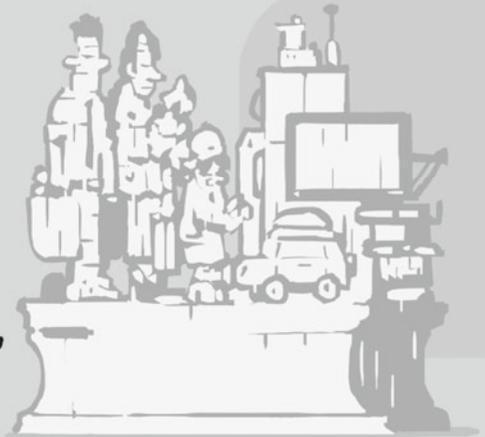
OF COURSE **ADAPTATION**  
WON'T NECESSARILY BE  
**EASY FOR ANYONE.**

THIS IS A THREAT  
TO MY **QUALITY**  
OF LIFE!

THIS IS A THREAT TO  
MY **ACTUAL LIFE.**



BUT IT WILL DEFINITELY BE **EASIER FOR THE WEALTHY...**



... THAN **FOR THE POOR.**



YOU CAN SEE THE **GAP BETWEEN RICH AND POOR**  
WHEN YOU LOOK AT **SEA LEVEL RISE...**

OH, NO!  
MY **SUMMER HOME!**



OH, NO!  
MY **FARM!**



... **HEAT WAVES...**

AT LEAST WE'VE GOT  
**A/C AND ICED MARGARITAS!**



AT LEAST IT WON'T  
BE SO **COLD** IN  
THE **WINTER.**



... **E\*TRME WEATHER...**

FLASH  
FLOODS?

DUST  
STORMS?

THIS 4X4  
HANDLES IT  
ALL.



OUR TIN ROOF  
DOUBLES AS A  
**FLOTATION**  
DEVICE.



**... HIGHER FOOD PRICES...**

**\$10 FOR A MOLTO  
FRAPPUCCINO?**

**GUESS I WON'T BUY  
ANOTHER UNTIL  
TOMORROW.**

**\$10 FOR A BAG  
OF RICE?**

**GUESS I WON'T  
BUY ANOTHER  
UNTIL NEXT  
MONTH.**

**... AND DISEASE OUTBREAKS.**

**AND THE IMPACT ON THE POOR IS ESPECIALLY UNFAIR SINCE THEY  
HAVEN'T CONTRIBUTED MUCH TO THE PROBLEM.**

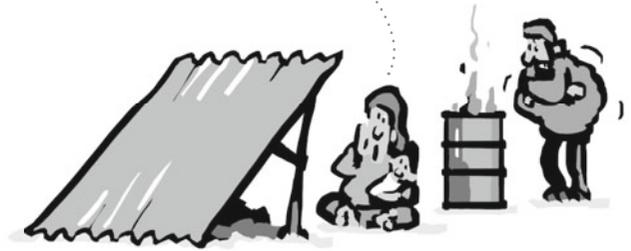
**MY CARBON  
FOOTPRINT  
IS MORE LIKE A  
TOEPRINT.**

FORTUNATELY, **ECONOMIC GROWTH** WILL LIKELY MEAN **MORE RICH PEOPLE AND FEWER POOR PEOPLE** IN THE DECADES AHEAD.



REMEMBER THE **HAPPY STORY** WE TOLD ON PAGE 4?

YEAH, TELL IT TO US **AGAIN!**



BUT EVEN THOSE WHO **BENEFIT** FROM ECONOMIC GROWTH WILL FACE **BIG CHALLENGES...**

I MISS ALL THAT **BIODIVERSITY.**

I MISS **BEACHES.**

WHADDYA MEAN I CAN'T EAT **MONEY?**



...AND THERE'S A CHANCE THAT EVEN THE RICH WILL BE **OVERWHELMED.**

ESPECIALLY TOWARDS THE **END OF THE CENTURY** AND BEYOND.



# CHAPTER 10

## BEYOND 2100

THE WORLD WILL  
CONTINUE **BEYOND**  
2100, YOU KNOW.

AT LEAST WE  
**HOPE SO!**



SO FAR WE'VE FOCUSED ON THE IMPACTS OF CLIMATE CHANGE **IN THIS CENTURY.**



I DON'T LIKE THIS BOOK!



IN OTHER WORDS, WE'VE FOCUSED ON HOW CLIMATE CHANGE WILL AFFECT **US...**



... AND OUR **CHILDREN AND GRANDCHILDREN.**



BUT NOW WE'RE GOING TO LOOK AT WHAT MIGHT HAPPEN IN THE **EXTRA LONG TERM.**

LIKE TO **OUR GREAT, GREAT, GREAT, GREAT GRANDCHILDREN,**



UNFORTUNATELY, EVEN IF WE WENT **COLD TURKEY**  
AND STOPPED EMITTING GREENHOUSE GASES **TODAY...**



... HUMAN-INDUCED CLIMATE CHANGE WOULD **CONTINUE BEYOND 2100.**



IN FACT, SEA LEVELS (AND MAYBE ALSO TEMPERATURES) WOULD  
**CONTINUE TO RISE FOR HUNDREDS OF YEARS.**

THE RISE WOULD JUST  
BE **SLOWER** THAN IF  
WE KEEP POLLUTING.

BUT  
**WHY?**



ONE REASON CLIMATE IMPACTS GO ON AND ON IS THAT CO<sub>2</sub> IS A **LONG-LIVED GAS.**

# LONG LIVE CO<sub>2</sub>!



WELL, THAT'S NOT REALLY **WHAT WE MEANT.**



ABOUT **HALF** OF THE CO<sub>2</sub> WE'RE EMITTING NOW WILL **STILL BE WARMING THE PLANET IN 100 YEARS...**



NYAA NYAA!

MOST OF THE REST WILL HAVE **DISSOLVED IN THE OCEANS...**

... **MAKING THEM MORE ACIDIC.**



... AND ABOUT **HALF OF THAT AMOUNT** WILL STILL BE AT IT IN **A THOUSAND YEARS.**



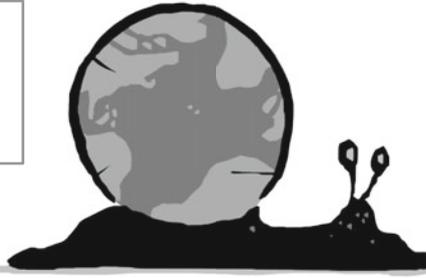
AS FAR AS HUMANS ARE CONCERNED, THAT'S PRETTY MUCH **FOREVER.**

LIKE **TATTOOS...**

... OR **NUCLEAR WASTE,**



ANOTHER REASON IS THAT **THE EARTH'S CLIMATE SYSTEM IS SLUGGISH.**



THIS MEANS THAT THE PLANET DOESN'T RESPOND **INSTANTANEOUSLY** TO CHANGES IN ENERGY BALANCE.



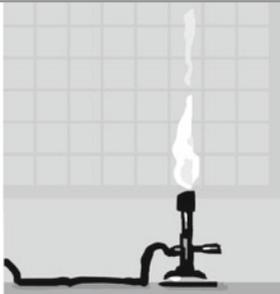
INSTEAD IT RESPONDS **GRADUALLY**...



... WHICH IN THIS CASE CAN MEAN **HUNDREDS IF NOT THOUSANDS OF YEARS.**



ONE ESPECIALLY **SLUGGISH** PART OF THE EARTH'S CLIMATE SYSTEM IS **SEA LEVEL RISE.**



OK CLASS, TODAY WE'RE GOING TO WATCH **ICE MELT.**

ZZZZZZZ



WE SAW IN CHAPTER 8 THAT SEAS ARE LIKELY TO RISE ABOUT **2 FEET BY 2100.**



BUT SEAS WILL CONTINUE TO RISE FOR **SEVERAL CENTURIES BEYOND THAT...**

LOW TIDE IN 2200...

... MIGHT EQUAL HIGH TIDE IN 2100.

... PARTLY BECAUSE OF CONTINUING **THERMAL EXPANSION...**

WE LEARNED ABOUT THAT ON PAGE 92,

... AND PARTLY BECAUSE ONCE GLACIERS **START TO MELT,** IT'S HARD TO TELL WHEN THEY'LL **STOP.**



SEA LEVEL RISE IS ESPECIALLY PROBLEMATIC BECAUSE SO MANY PEOPLE LIVE **NEAR THE COAST**.

REAL ESTATE IS ALL ABOUT **LOCATION, LOCATION, LOCATION**.



IF THE ENTIRE **GREENLAND ICE SHEET** MELTS, THE SEAS WILL RISE BY ABOUT **20 FEET**.



IF THE **WEST ANTARCTIC ICE SHEET** MELTS, THEY'D RISE **ANOTHER 20 FEET**.

GOODBYE, **FLORIDA**.



GOODBYE, **KOLKATA**.



BUT REMEMBER, MELTING MILE-THICK ICE SHEETS WOULD TAKE **MANY HUNDREDS OF YEARS...**

... AND **WHO KNOWS** WHAT THE WORLD WILL LOOK LIKE IN **HUNDREDS OF YEARS?**

THE WORLD POPULATION COULD BE **2 BILLION...**

... OR **36 BILLION.**



WE COULD DISCOVER **TECHNOLOGICAL MIRACLES...**

... OR RETURN TO THE **STONE AGE.**



WE COULD HAVE **UNDERWATER CITIES...**

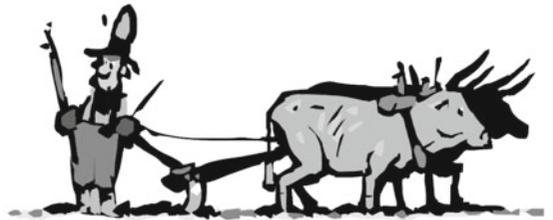
... OR WIND UP **SWIMMING WITH THE FISHES.**



TO SEE HOW HARD IT IS TO LOOK **BEYOND 2100**, IMAGINE SOMEONE IN **1900...**



HOWDY, **STRANGER!**



... TRYING TO ANTICIPATE **TODAY'S WORLD.**

**ANTIBIOTICS?**

**COMPUTERS?**

**SATELLITE-GUIDED TRACTORS?**

WHAT KIND OF **NONSENSE** ARE YOU **TALKING?**



INDEED, WHEN THE SWEDISH CHEMIST **ARRHENIUS** FIRST STUDIED CLIMATE CHANGE **100 YEARS AGO...**

... HE THOUGHT THE RESULTS WOULD BE **GOOD.**

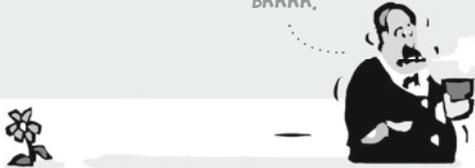
"THE **INCREASING PERCENTAGE OF [CO<sub>2</sub>]** IN THE ATMOSPHERE,...

... WILL BRING FORTH MUCH MORE **ABUNDANT CROPS** THAN AT PRESENT."



OF COURSE, HE LIVED IN **SWEDEN.**

BRRRR,



ALL OF THIS JUST SHOWS **HOW TOUGH IT IS TO MAKE PREDICTIONS...**

... **ESPECIALLY ABOUT THE FUTURE!**

IN 100 YEARS WE'LL ALL BE **BETTER OFF** BECAUSE OF **ECONOMIC GROWTH...**

... **UNLESS WE'RE WORSE OFF** BECAUSE OF **ENVIRONMENTAL DEGRADATION.**



IN SUM, ALTHOUGH THE **GENERAL TRAJECTORY** FOR THE EARTH'S CLIMATE IS PRETTY CLEAR...



I'M JUST GETTING **WARMED UP.**

... THE **LONG TIME SPAN** ASSOCIATED WITH GLOBAL WARMING...

THE CHOICES **YOU MAKE** WILL HAVE CONSEQUENCES FOR YOUR **GREAT, GREAT, GREAT GRANDCHILDREN.**



... IS ONE OF THE **TWO MAJOR ISSUES** THAT ADD **UNCERTAINTY** TO THE PROBLEM OF CLIMATE CHANGE.

WHAT'S THE **OTHER MAJOR ISSUE?**

**UNCERTAINTY.**



# CHAPTER 11

## UNCERTAINTY

WELL, IF YOU WANT  
TO BE **CERTAIN...**

... WE'LL JUST HAVE TO  
**WAIT AND SEE.**



IN THIS CHAPTER WE'RE GOING TO TAKE  
A BREAK FROM **LIKELY OUTCOMES**...

TODAY WAS THE  
USUAL **BLAH,**  
**BLAH, BLAH,**



... AND THINK FOR A BIT ABOUT  
**UNLIKELY OUTCOMES.**

THE CEO GOT  
FIRED AND  
BURNED DOWN  
THE BUILDING!



CONGRATULATIONS!



CONGRATULATIONS!



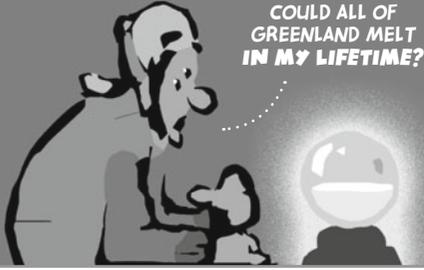
I JUST GOT  
IN A **FENDER  
BENDER...**



... WITH  
AN **ALIEN  
SPACECRAFT.**



WHEN IT COMES TO CLIMATE,  
**UNLIKELY OUTCOMES** ARE, WELL,  
**UNLIKELY.**



THAT WOULD BE  
**E\*CEPTIONALLY  
UNLIKELY.**



BUT NO MATTER HOW YOU **MEASURE THE ODDS...**

... **UNLIKELY DOESN'T  
MEAN IMPOSSIBLE.**

THESE ODDS  
ARE LESS THAN  
**1 IN 3.**



THESE ODDS  
ARE LESS THAN  
**1 IN 10.**



THESE ODDS  
ARE LESS THAN  
**1 IN 100.**



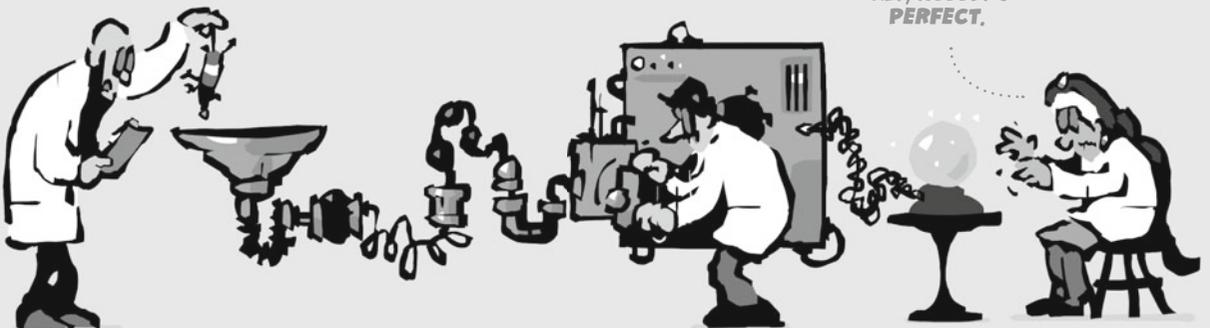
THESE ODDS ARE LESS THAN  
**1 IN 100,000,000.**



DUDE,  
**I WON THE  
LOTTERY!**



WE CAN SEE THIS BY LOOKING AT  
**PAST PREDICTIONS MADE BY CLIMATE SCIENTISTS.**





WHILE MANY SCIENTIFIC PREDICTIONS ABOUT CLIMATE CHANGE HAVE **HIT THE TARGET...**



WE THOUGHT **TEMPERATURES** WOULD RISE THIS MUCH...

... **AND THEY DID.**



WE THOUGHT **SEAS** WOULD RISE THIS MUCH...

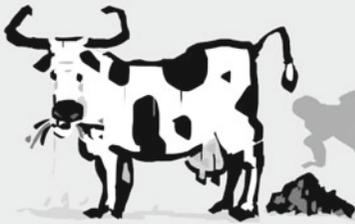
... **AND THEY DID.**



... **OTHERS HAVE MISSED...**



... **BOTH FOR BETTER...**



WE THOUGHT **METHANE** WOULD RISE THIS MUCH...

... **BUT IT ROSE LESS.**



... **AND FOR WORSE.**

WE THOUGHT **ARCTIC SEA ICE** WOULD MELT...

... **BUT NOT THIS FAST.**



IN OTHER WORDS, SOME SCENARIOS SCIENTISTS THOUGHT WERE **UNLIKELY**...

... **ACTUALLY** CAME TO PASS.

**XYZ**  
IS VERY  
**UNLIKELY.**

NEWS FLASH:  
**XYZ JUST  
HAPPENED!**



MADDENING THOUGH IT IS, THIS SORT OF UNCERTAINTY IS **UNAVOIDABLE.**





THE TRUTH IS, THE EARTH'S CLIMATE SYSTEM IS  
**EXTREMELY COMPLICATED...**

I THINK THAT'S  
**EVERYTHING.**

WAIT, THERE'S  
**MORE!**

... SO NO MATTER HOW MUCH **DETAIL** WE BUILD INTO OUR **COMPUTER MODELS...**

SOLAR  
VARIATION

OCEAN  
CIRCULATION

CARBON  
CYCLE

MELTING  
PERMAFROST

CLOUD  
HEIGHT

CLOUD  
EXTENT

CLOUD  
PARTICLE SIZE

... WE WILL **NEVER** BE ABLE TO PREDICT THE FUTURE WITH  
**ABSOLUTE CERTAINTY.**

WE'RE **PROBABLY**  
LOOKING AT **4°C**  
THIS CENTURY...

... BUT **MAYBE** IT'LL  
BE ONLY **3°C...**

... AND **MAYBE** AS  
MUCH AS **5° OR 6°C.**

AND THAT LEAVES US WITH  
A **CONUNDRUM**.



IF REALITY TURNS OUT TO BE **BETTER**  
THAN WE'D THOUGHT...

CLIMATE SENSITIVITY  
IS **LOW**...

... ECOSYSTEMS ARE  
**RESILIENT**...

... PEOPLE FIND WAYS  
TO **ADAPT**.

WHEW, WE  
**DODGED A BULLET**  
BACK THERE.



... THEN BUSINESS AS USUAL MIGHT  
**NOT BE SO BAD.**

THANKS TO RAPID  
ECONOMIC GROWTH,  
WE ALL GET **MORE**  
**CAKE**...

... **AND THERE'S NOT TOO**  
MUCH EXTRA SUFFERING FROM  
CLIMATE CHANGE.



BUT IF REALITY TURNS OUT TO BE **WORSE**  
THAN WE'D THOUGHT...

CLIMATE SENSITIVITY  
IS **HIGH...**

...ICE SHEETS  
**DISINTEGRATE...**

...THE AMAZON  
**BURNS UP...**

...BREAD BASKETS  
BECOME **DUST**  
**BOWLS.**

... THEN BUSINESS  
AS USUAL COULD BE  
**CATASTROPHIC.**

INSTEAD OF  
**MORE CAKE...**

... ALL WE GOT  
WAS **TRAGEDY.**

ALL THIS TALK ABOUT  
**POTENTIAL CATASTROPHES...**

... SHOULD MAKE YOU THINK  
ABOUT **INSURANCE**,

I'M  
SCARED.  
WHAT  
CAN I DO?

TALK TO MY  
SISTER...

... SHE'S A BROKER  
AT **AETNA**,

FOR EXAMPLE, WHILE IT'S  
**UNLIKELY** THAT YOU'LL GET INTO  
A **HORRIFIC ACCIDENT...**

... OR BECOME **DEATHLY ILL...**

ESPECIALLY WITH  
AN **ALIEN**.

**MEDIC!**

IT'S ANOTHER CASE OF  
**STOCHASTIC ANXIETY  
DISORDER.**

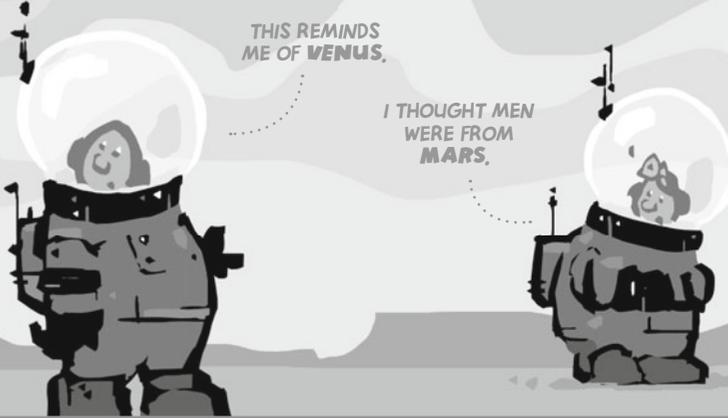
... IT'S A GOOD IDEA TO **BUY INSURANCE**, JUST IN CASE.

INSURANCE GIVES YOU  
A WAY TO **PAY A BIT  
MORE NOW...**

... TO AVOID **TOTAL  
DISASTER IN THE  
FUTURE.**

**BAD TURNS  
INTO A BIT  
LESS BAD.**

SIMILARLY, ALTHOUGH IT'S **UNLIKELY** THAT **CLIMATE IMPACTS** WILL BE **CATASTROPHIC**...



...IT'S A GOOD IDEA TO BUY INSURANCE, **JUST IN CASE.**

I LIKE **SCIENCE FICTION.**

BUT WE DON'T WANT OUR **KIDS** TO **LIVE THROUGH IT.**



NOW, YOU CAN BUY INSURANCE FOR **ALL KINDS OF THINGS**...

I'VE GOT **LIFE** INSURANCE...

...**PET** INSURANCE...

...**HOME** INSURANCE...

...**FLOOD** INSURANCE...

...EVEN **ALIEN ABDUCTION** INSURANCE.



... BUT HOW DO YOU BUY INSURANCE FOR THE **WHOLE PLANET**?

IT TURNS OUT THAT OUR  
**BEST INSURANCE POLICY...**

... IS TO **REDUCE EMISSIONS OF CO<sub>2</sub>**  
AND OTHER GREENHOUSE GASES.

THE MORE WE  
REDUCE **NOW...**

... THE LESS LIKELY  
WE'LL MEET  
**CATASTROPHE.**

AND WE'LL LEARN MORE ABOUT THAT IN THE **NEXT PART OF THIS BOOK.**

IF WE GIVE UP A SMALL  
PIECE OF CAKE...

... WE CAN GET  
**PEACE OF MIND.**



**PART  
THREE**  
*ACTIONS*



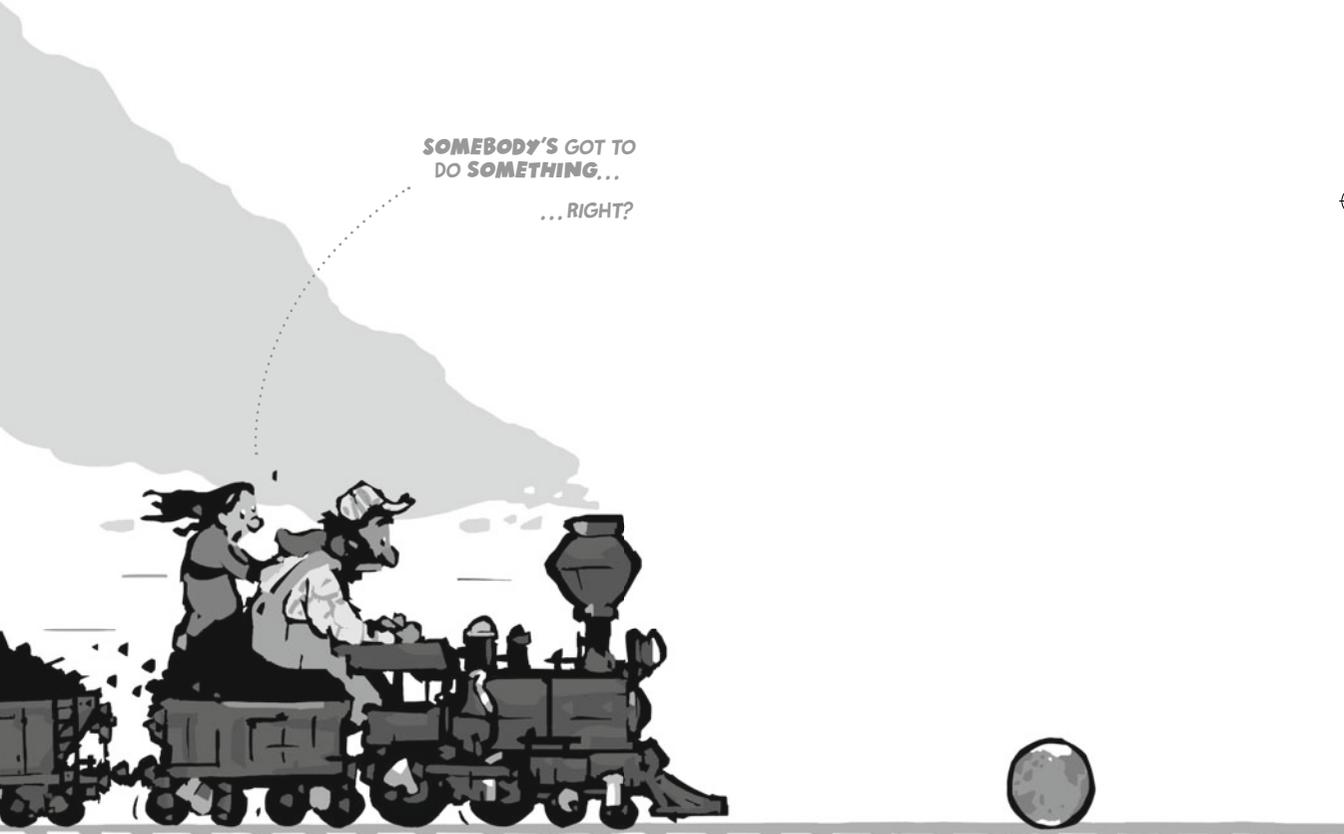


# CHAPTER 12

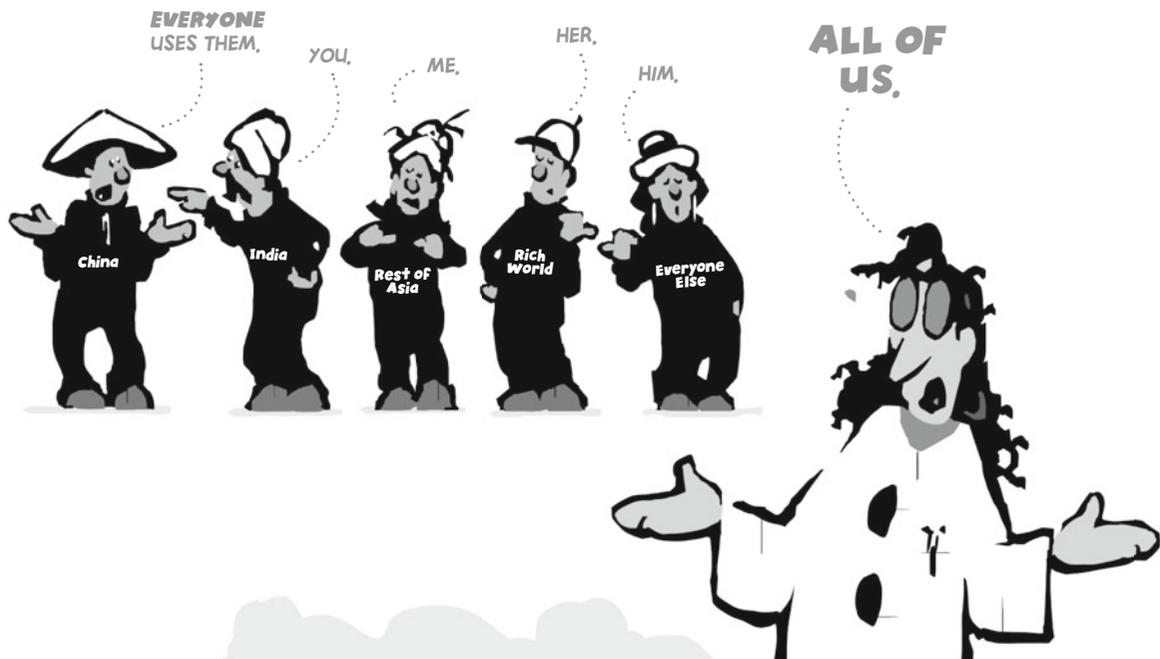
## THE TRAGEDY OF THE COMMONS

**SOMEBODY'S GOT TO  
DO SOMETHING...**

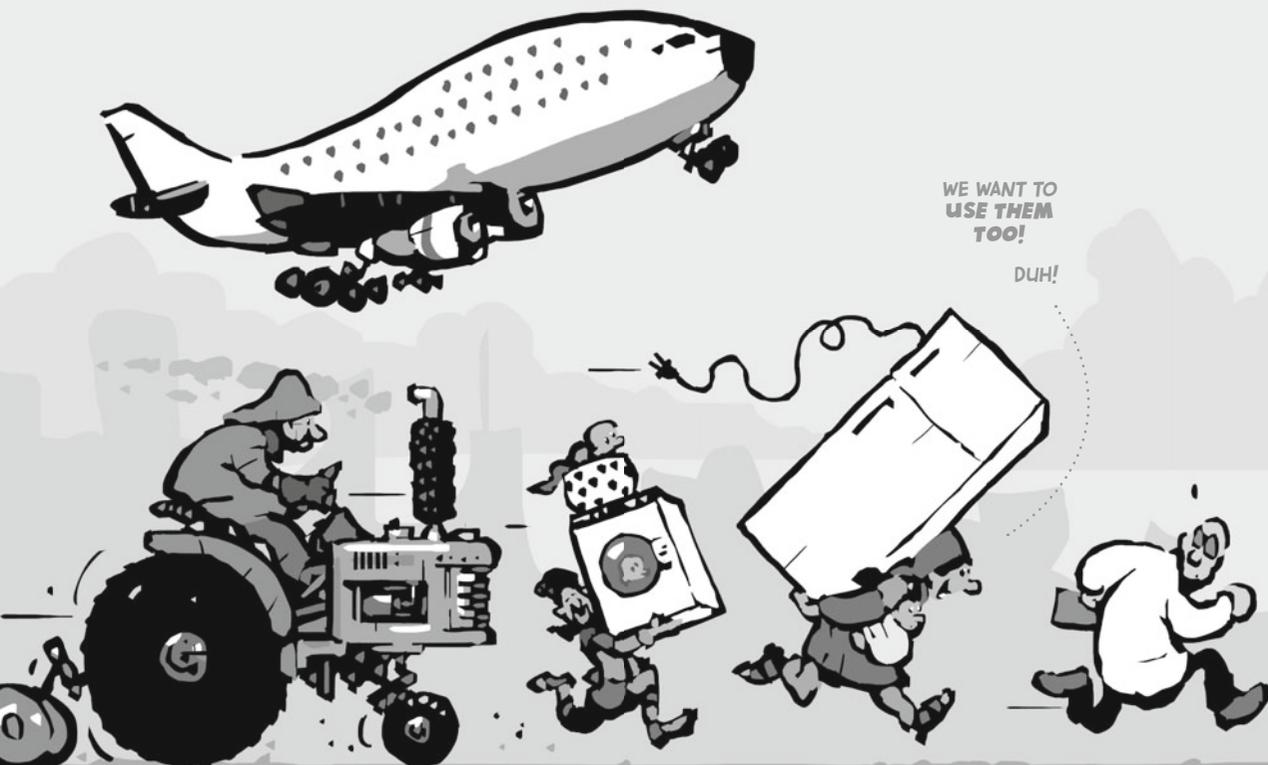
... RIGHT?



**FOSSIL FUELS ARE A KEY INGREDIENT  
IN MODERN ECONOMIES...**



**...SO IT'S NOT GOING TO BE EASY TO SLOW DOWN  
THE GROWTH IN FOSSIL FUEL CONSUMPTION.**





BUT JUST BECAUSE TAKING ACTION  
MAKES GOOD SENSE...

... DOESN'T MEAN IT WILL **ACTUALLY HAPPEN.**

I'M TRYING TO  
STOP SMOKING...



... BUT  
I JUST **CAN'T!**



THAT'S A PROBLEM FOR **INDIVIDUALS,**  
BUT IT'S AN EVEN BIGGER PROBLEM FOR **GROUPS...**

WE'RE TRYING TO  
REDUCE CO<sub>2</sub>...



... BUT  
WE JUST **CAN'T!**



... BECAUSE OF THE **TRAGEDY OF THE COMMONS.**

INDIVIDUAL  
SELF-INTEREST...



... CAN LEAD TO  
BAD OUTCOMES  
FOR THE GROUP  
AS A WHOLE.



THE IDEA BEHIND THE TRAGEDY OF THE COMMONS GOES BACK AT LEAST AS FAR AS **ARISTOTLE**...



SELF-INTEREST LEADS PEOPLE TO PICK UP AFTER THEIR **OWN DOG** IN THEIR **OWN BACKYARD**...

... BUT LOTS OF PEOPLE DON'T PICK UP AFTER THEIR DOG IN **PUBLIC PLACES**.



THE TRAGEDY OF THE COMMONS IS THE **ROOT CAUSE** OF ENVIRONMENTAL PROBLEMS LIKE **LITTERING...**

HEY, HOW ABOUT USING YOUR **PLASTIC BAG** TO PICK UP YOUR **DOG POOP?**



...AND **OVERFISHING...**

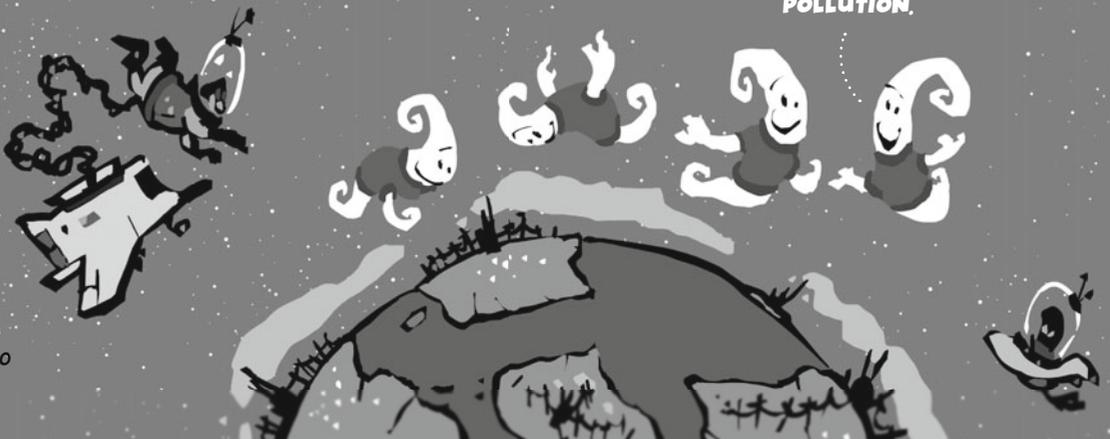


...AND **AIR POLLUTION...**



...AND **CLIMATE CHANGE.**

IT'S GLOBAL AIR POLLUTION.



YOU CAN SEE THE TRAGEDY OF THE COMMONS IN YOUR OWN **PERSONAL DECISIONS...**

SURE I'LL **GENERATE CARBON EMISSIONS** IF I FLY TO HAWAII...

... BUT I REALLY WANT TO GO TO HAWAII!



... AND IN DECISIONS MADE BY **ENTIRE COUNTRIES** WHEN THEY FAIL TO SIGN CLIMATE AGREEMENTS...

AMERICAN **SELFISH JERK!**



... OR FAIL TO LIVE UP TO AGREEMENTS THEY **ALREADY SIGNED...**

CANADIAN **HYPOCRITE!**



... OR FAIL TO DO MUCH BEYOND **BLAMING EVERYONE ELSE.**



FORTUNATELY, THERE ARE  
**TWO PIECES OF GOOD NEWS.**

ONE IS THAT **SELF-INTEREST IS NOT ALL BAD.**

"IT IS NOT FROM THE  
**BENEVOLENCE** OF THE BUTCHER,  
THE BREWER, OR THE BAKER THAT  
WE EXPECT OUR DINNER,...

... BUT FROM **THEIR  
REGARD TO THEIR  
OWN INTEREST.**"



FOR EXAMPLE, SOME COUNTRIES  
HAVE **STRONG INCENTIVES  
FOR ADAPTATION...**

IF WE DON'T ADAPT,  
WE'LL BE **FLOODED...**

... SO LET'S **BUILD  
A SEAWALL!**



... AND SOMETIMES **SELF-INTEREST** HAPPENS TO COINCIDE WITH **EMISSIONS REDUCTIONS.**

WE WANT TO  
CLEAN UP **LOCAL  
POLLUTION...**

... AND  
IMPROVE **ENERGY  
SECURITY...**

... AND **BURNING  
LESS FOSSIL FUELS  
WILL HELP US.**



THE OTHER PIECE OF GOOD NEWS IS THAT THE TRAGEDY OF THE COMMONS IS **NOT INEVITABLE.**



HISTORY SHOWS THAT **INTERNATIONAL AGREEMENTS** ARE IN FACT **POSSIBLE...**



THE **MONTREAL PROTOCOL** HELPED PROTECT THE OZONE LAYER.



AND COUNTRIES HAVE ALSO COOPERATED ON **FREE TRADE AGREEMENTS...**



...AND **FISHING TREATIES...**



...AND **ARMS CONTROL AGREEMENTS.**



...AND IN CHAPTER 14 WE'LL SEE WHAT A **CLIMATE AGREEMENT** MIGHT LOOK LIKE,

HOW ABOUT A GLOBAL AGREEMENT ON **CARBON TAXES?**



OR A **BINDING CAP AND TRADE TREATY?**

BUT TO OVERCOME THE TRAGEDY OF THE COMMONS,  
AN AGREEMENT NEEDS TO HAVE **TEETH...**



CARBON SCOFFLAWS WILL FACE **INTERNATIONAL SANCTIONS!**



... AND PERHAPS EVEN AN **ELEMENT OF FORCE.**



**FREEZE!**

SIGN THIS CLIMATE AGREEMENT  
OR WE'LL IMPOSE **BORDER  
TAX ADJUSTMENTS** ON  
YOUR COUNTRY.



AND IF YOU  
DON'T UNDERSTAND  
THAT, **READ THE  
GLOSSARY!**

AND THE DIFFICULTY OF **GETTING EVERYONE TO AGREE...**

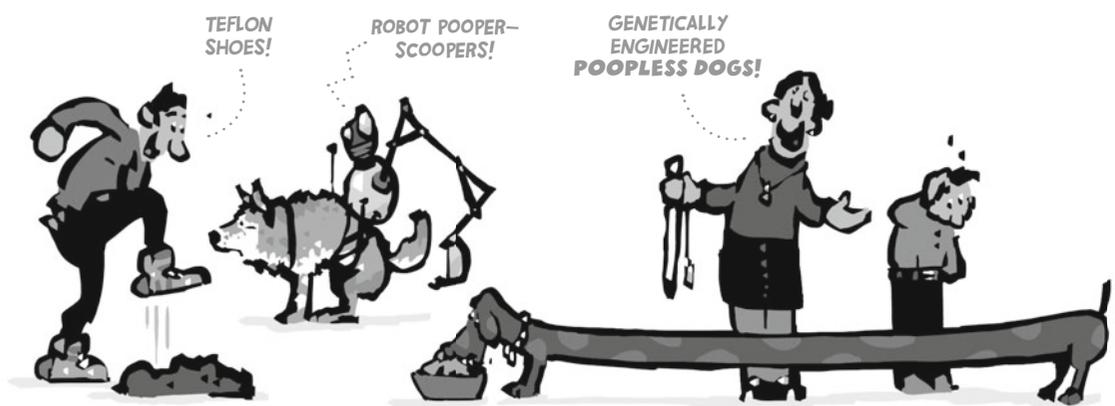


**NO FAIR!**  
HER FINE SHOULD  
BE **BIGGER THAN  
MINE!**



**NO FAIR!**  
THIS BURDENS  
MY COUNTRY **MORE  
THAN YOURS!**

... LEADS SOME FOLKS TO HOPE FOR A **MIRACLE CURE.**



**TEFLON  
SHOES!**

**ROBOT POOPER-  
SCOOPERS!**

**GENETICALLY  
ENGINEERED  
POOPLESS DOGS!**

# CHAPTER 13

## TECHNO-FIX



**SOME IDEAS FOR TACKLING CLIMATE CHANGE SOUND LIKE SCIENCE FICTION...**



**... LIKE FERTILIZING THE OCEANS WITH IRON...**

THAT STIMULATES THE GROWTH OF PLANKTON, WHICH ABSORBS CO<sub>2</sub>.

WE JUST NEED THE PLANKTON TO DIE AND SINK TO THE BOTTOM.



**... SPRAYING SALTWATER INTO THE AIR...**

THAT INCREASES THE EARTH'S ALBEDO BY CREATING CLOUDS.

WE JUST NEED AN ARMADA OF 30,000 SELF-GUIDED SHIPS.



**... PUMPING SULFUR DIOXIDE INTO THE ATMOSPHERE...**

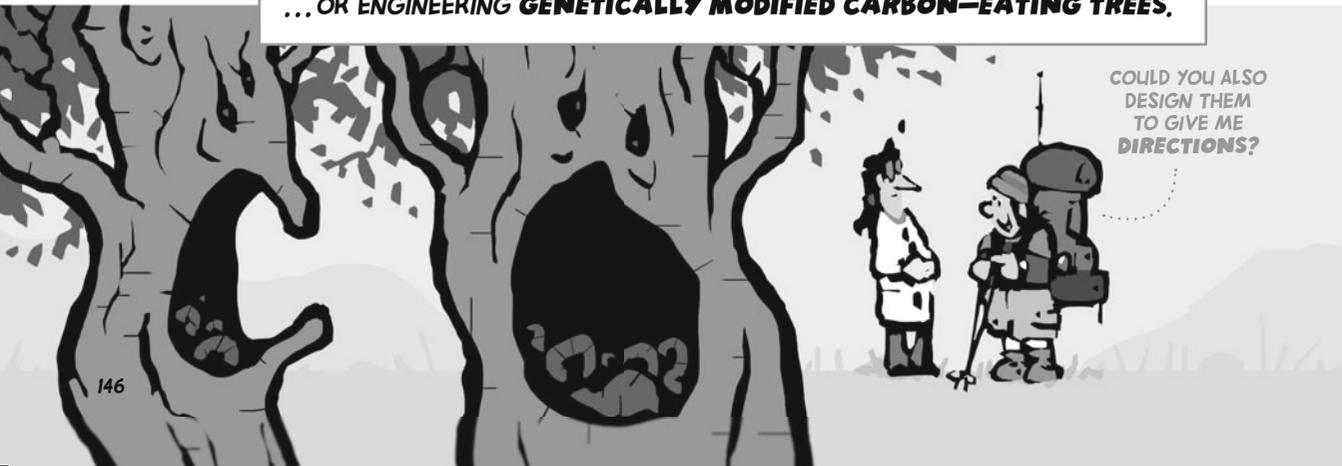
SULFUR PARTICLES REFLECT INCOMING SUNLIGHT.

WE JUST NEED SOME 18-MILE-LONG GARDEN HOSES.



**... OR ENGINEERING GENETICALLY MODIFIED CARBON-EATING TREES.**

COULD YOU ALSO DESIGN THEM TO GIVE ME DIRECTIONS?



SOME PEOPLE THINK OF THESE **GEOENGINEERING** IDEAS AS A **PAINLESS CURE—ALL...**

"PERHAPS THE **SINGLE BEST OBJECTION** TO THE GARDEN HOSE IDEA,...

... IS THAT IT'S **TOO SIMPLE AND TOO CHEAP.**"

... BUT THAT VIEW **ISN'T TERRIBLY REALISTIC.**

EVEN IF WE COULD GET IT **WORKING...**

...IT WON'T STOP **OCEAN ACIDIFICATION.**

AND WHAT ABOUT **UNINTENDED CONSEQUENCES?**

THERE IS, HOWEVER, A **MUCH MORE PROMISING SORT OF TECHNO-FIX.**

WHAT IS IT, **SPACE MIRRORS?**

NO, SILLY. IT'S **CHEAP, CLEAN ENERGY.**

IF WE CAN DEVELOP **CLEAN ENERGY**  
THAT'S **CHEAPER THAN FOSSIL FUELS...**

ENERGY FROM  
FOSSIL FUELS  
IS **CHEAP...**

... BUT MY  
**CLEAN ENERGY**  
IS **CHEAPER.**



... THEN IT WILL BE IN EVERYONE'S **SELF-INTEREST**  
TO ABANDON COAL, OIL, AND NATURAL GAS.

NO **TRAGEDY OF**  
THE **COMMONS.**

NO **PROBLEM!**



AND CHEAP, CLEAN ENERGY  
WOULD NOT ONLY HELP  
STABILIZE THE CLIMATE.

TAKE THAT,  
BUSINESS AS  
USUAL!



IT WOULD ALSO **IMPROVE LIVING STANDARDS**  
FOR BILLIONS OF PEOPLE,...

**CHEAP ENERGY**  
COULD BRING US  
REFRIGERATION...

... AND CLEAN UP **LOCAL AIR POLLUTION.**

... **TRANSPORTATION**...

... AND ACCESS TO  
THE **INTERNET.**

**CLEAN ENERGY**  
COULD BRING US  
**BLUE SKIES.**



SOUNDS **GREAT**, RIGHT?

SO...

... WHAT IS THIS  
**CHEAP, CLEAN  
ENERGY?**

**GOOD  
QUESTION!**



FROM A CLIMATE PERSPECTIVE, **ENERGY IS CLEAN** IF IT **DOESN'T INCREASE ATMOSPHERIC CO<sub>2</sub> CONCENTRATIONS.**

FOSSIL FUELS **PUSH UP** THE **KEELING CURVE.**

CLEAN ENERGY SOURCES **DON'T.**



THIS INCLUDES **RENEWABLE ENERGY SOURCES** LIKE **SOLAR POWER...**



... **HYDROPOWER...**



... **WIND POWER...**



... **GEOTHERMAL POWER...**



... AND **TIDAL POWER.**



IT **ALSO** INCLUDES ALTERNATIVES  
LIKE **NUCLEAR POWER...**

...AND SOME **BIOFUELS...**

FROM A  
**CLIMATE**  
PERSPECTIVE,  
I'M **CLEAN.**

GROWING **BIOFUELS**  
CONSUMES **CO<sub>2</sub>...**

... SO BURNING THEM  
CAN BE **CARBON**  
**NEUTRAL.**

...AS WELL AS PROPOSALS SUCH AS **CARBON CAPTURE AND STORAGE,**

IF WE BURN FOSSIL FUELS  
AND PUMP THE **CO<sub>2</sub>**  
**UNDERGROUND...**

...IT **WON'T**  
**END UP IN THE**  
**ATMOSPHERE.**

YOU CAN THINK OF **ENERGY EFFICIENCY** AS A FORM OF **CLEAN ENERGY, TOO.**

IF WE FIND WAYS TO  
**REDUCE OUR ENERGY**  
**CONSUMPTION...**

... WE CAN GENERATE  
**"NEGAWATTS."**

THERE ARE ALL SORTS OF **CHALLENGES** FACING THESE CLEAN ENERGY OPTIONS...

THE SUN **DOESN'T** ALWAYS SHINE.

THE WIND **DOESN'T** ALWAYS BLOW.



... BUT THE **MAIN CHALLENGE** FACING ALL OF THEM CAN BE SUMMED UP IN **ONE WORD**.

# MONEY



IT MIGHT FEEL LIKE **FOSSIL FUELS ARE EXPENSIVE.**

\$4 A GALLON!

\$180 A MONTH!



BUT FOSSIL FUELS ARE STILL USUALLY THE **CHEAPEST OPTION FOR BUYERS...**

...AND FOR **SELLERS.**

THAT'S WHY WE KEEP BUYING THEM.

THAT'S WHY WE KEEP SELLING THEM.



IN PART THAT'S BECAUSE OF ALL THE **INVESTMENTS** OVER THE PAST CENTURY...

IT COST ME A LOT TO BUILD THIS COAL PLANT...

... BUT NOW THAT IT'S BUILT **MY OPERATING COSTS ARE LOW.**

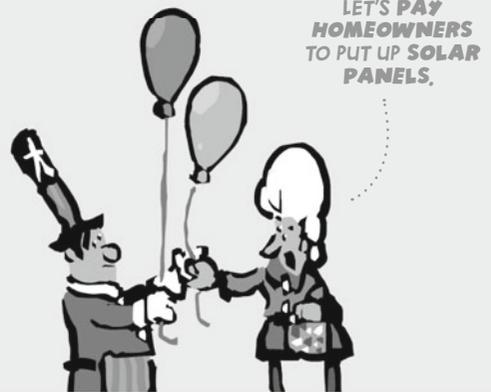


... AND BECAUSE OF ONGOING **FOSSIL FUEL SUBSIDIES** ESTIMATED AT **\$400 BILLION PER YEAR.**

IN ORDER TO MAKE CLEAN ENERGY **MORE COMPETITIVE...**



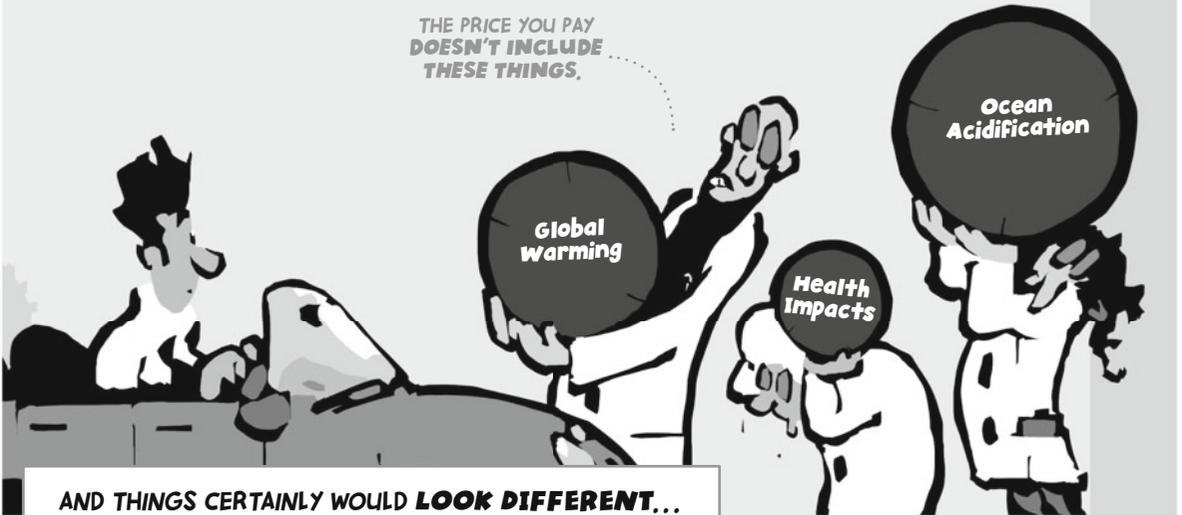
... MANY PEOPLE WANT THE **GOVERNMENT** TO **SUBSIDIZE RENEWABLES.**



MANY ECONOMISTS, HOWEVER, EMPHASIZE THAT FOSSIL FUELS ARE **NOT ACTUALLY AS CHEAP AS THEY APPEAR...**



... BECAUSE THEIR PRICE DOESN'T INCLUDE THE **COSTS OF POLLUTION.**

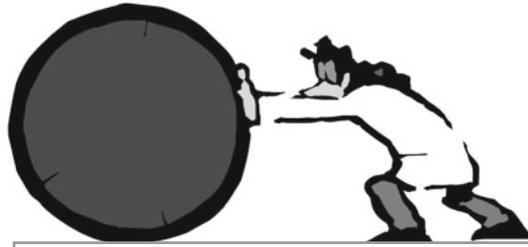


AND THINGS CERTAINLY WOULD **LOOK DIFFERENT...**

... IF WE TOOK STEPS TO **INTERNALIZE THOSE EXTERNAL COSTS.**



**THAT'S WHY MOST  
ECONOMISTS AGREE...**



**... THAT THE BEST WAY TO MAKE CLEAN ENERGY  
MORE COMPETITIVE WITH FOSSIL FUELS...**



**... IS TO MAKE FOSSIL FUELS MORE EXPENSIVE.**

**WE NEED  
TO LEVEL  
THE PLAYING  
FIELD.**



**ECONOMISTS LIKE  
THIS MARKET-BASED  
APPROACH...**



**PUTTING A PRICE  
ON CARBON...**

**... WILL ENCOURAGE  
BUSINESSES AND  
CONSUMERS TO **CHANGE**  
THEIR BEHAVIOR.**



**... BECAUSE IT PROMISES TO BOTH  
REDUCE THE CONSUMPTION OF DIRTY FUELS IN THE SHORT RUN...**

**IT'S IN OUR  
SELF-INTEREST  
TO ABANDON YOU,**

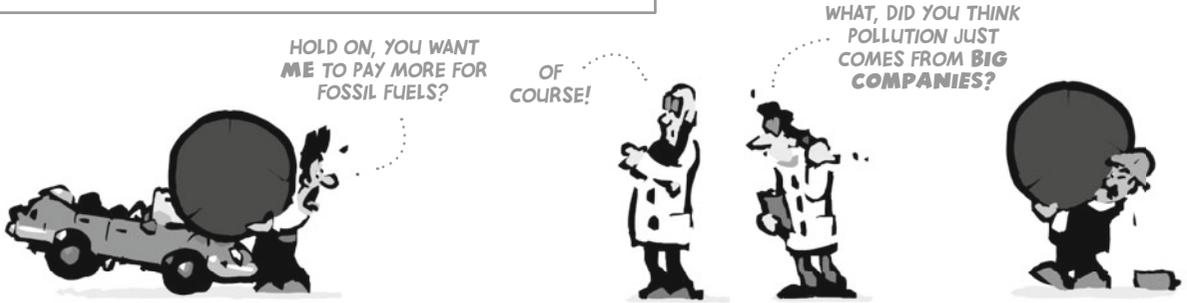


**... AND PROMOTE THE DEVELOPMENT OF NEW TECHNOLOGIES IN THE LONG RUN.**

**IT'S IN YOUR  
SELF-INTEREST  
TO INVEST IN CLEAN  
ENERGY.**



OF COURSE, THE IDEA OF MAKING FOSSIL FUELS MORE EXPENSIVE IS **CONTROVERSIAL**,



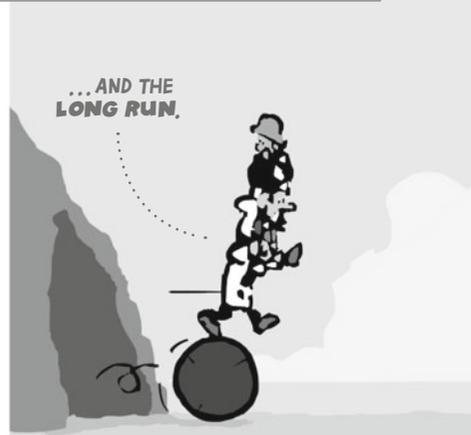
IN PART THAT'S BECAUSE THE **LIGHT AT THE END OF THE TUNNEL...**



...IS AT THE **END OF A TUNNEL**.

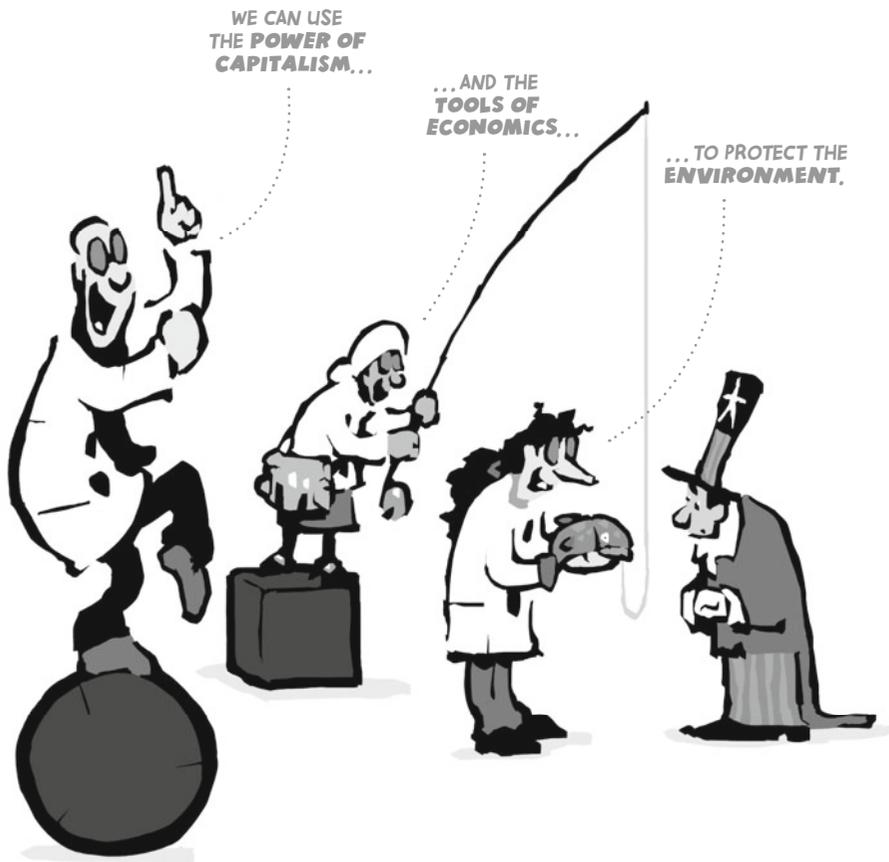


SO WE'RE GOING TO SPEND THE NEXT CHAPTER PROVIDING SOME **ILLUMINATION**.



# CHAPTER 14

## PUTTING A PRICE ON CARBON



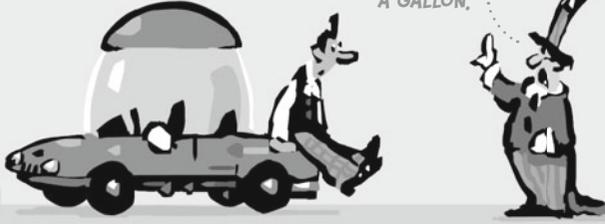
TACKLING CLIMATE CHANGE  
WILL PROBABLY REQUIRE  
ACTION BY **VOTERS** AND  
**GOVERNMENTS**.

WE'VE GOT TO  
**WORK TOGETHER**  
TO OVERCOME THE  
**TRAGEDY OF THE  
COMMONS**.

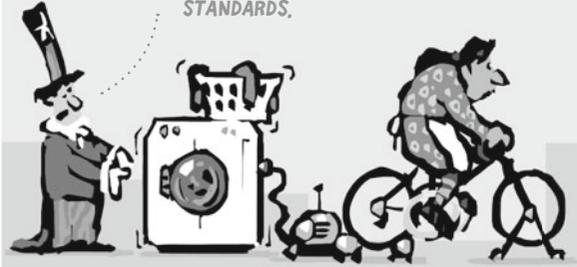


THE TWO MAIN POLICY OPTIONS ARE  
**DIRECT REGULATIONS...**

NEW CARS **MUST**  
AVERAGE 40 MILES  
A GALLON.



APPLIANCES **MUST**  
MEET NEW EFFICIENCY  
STANDARDS.



POWER COMPANIES  
**MUST** USE 25%  
RENEWABLES.



IF YOU **MUST**  
KNOW...

... THESE POLICIES ARE  
ALSO CALLED **COMMAND  
AND CONTROL**.



... AND **MARKET-BASED APPROACHES**  
LIKE **CARBON TAXES** AND **CAP AND TRADE SYSTEMS**.

THE WAY THESE POLICIES  
REDUCE POLLUTION...

... IS BY **MAKING  
POLLUTING  
EXPENSIVE**.



ONE DRAWBACK OF **DIRECT REGULATIONS** IS THAT THEY CAN BE PRETTY **HEAVY-HANDED**.

**ARRGH!**

YOU **MUST** USE THIS KIND OF **LIGHT BULB...**

...AND THIS KIND OF **CAR...**

...AND THIS KIND OF **TOILET...**



IN CONTRAST, MARKET-BASED APPROACHES OFFER MORE **FLEXIBILITY**.

WE'RE NOT GOING TO **FORCE** YOU TO DO **ANYTHING**.

WE'RE JUST GOING TO **MAKE POLLUTING EXPENSIVE...**

...AND LET YOU RESPOND **AS YOU SEE FIT**.

WELL, AT LEAST YOU'RE **NOT MICROMANAGING ME**.



THEY ALSO PROMOTE **CONSERVATION AND INNOVATION...**

I'M NOT GOING TO BUY THAT **HUMMER...**

... I'M GOING TO BUY THIS **SUPER-EFFICIENT HYBRID**.



... AND THEY DO ALL THIS BY **PUTTING A PRICE ON CARBON**.

RIGHT NOW **EMITTING CO<sub>2</sub> IS FREE**.

THIS CHAPTER IS ABOUT HOW TO **CHANGE THAT**.



THE OBVIOUS WAY TO PUT A PRICE ON CARBON IS WITH A **CARBON TAX**...

A **TAX**?

NOW YOU'VE GOT OUR ATTENTION.

... LIKE THE ONE IN **BRITISH COLUMBIA**.

I DON'T LIKE TO **BRAG**, BUT WE HAVE THE **BEST CLIMATE POLICY IN THE WORLD**.

THE B.C. CARBON TAX APPLIES TO "UPSTREAM" BUSINESSES LIKE **OIL REFINERIES** AND **POWER PLANTS**...

THE TAX IS **\$30 PER TON** OF CO<sub>2</sub>...

... EQUAL TO ABOUT **\$0.30 PER GALLON** OF GASOLINE...

... OR **\$0.03 PER KILOWATT-HOUR** OF COAL-FIRED POWER.

... BUT THOSE COMPANIES MOSTLY **PASS THE TAX ALONG TO CONSUMERS**.

THE TAX GIVES US AN INCENTIVE TO USE **LESS FOSSIL FUELS**...

... AND NOW YOU HAVE AN INCENTIVE, **TOO**.

**SORRY**, BUT THAT'S HOW MARKET FORCES WORK.

LUCKILY, THERE ARE **CLEVER WAYS TO REDUCE THESE BURDENS**.

THE CARBON TAX IN B.C. IS ESPECIALLY CLEVER BECAUSE THE GOVERNMENT USES THE TAX REVENUE...



LOOK AT THESE BILLIONS OF EXTRA DOLLARS, EH?

...TO REDUCE EXISTING TAXES ON JOBS, INCOME, AND INVESTMENT.

RAISING TAXES ON THINGS WE WANT LESS OF...



...ALLOWS US TO LOWER TAXES ON THINGS WE WANT MORE OF.



THERE ARE, OF COURSE, OTHER WAYS TO "RECYCLE" THE REVENUE FROM A CARBON TAX...

LET'S INVEST IN R&D...



...OR PROMOTE ENERGY EFFICIENCY...



...OR PAY DOWN THE DEFICIT...



...OR GIVE EVERYONE A DIVIDEND CHECK.



... BUT WHAT THEY ALL HAVE IN COMMON IS THAT THE REVENUE CAN BE PUT TO GOOD USE.

THOSE GOOD USES ARE ONE OF THE SIDE BENEFITS OF CARBON TAXES...



... IN ADDITION TO THE MAIN BENEFIT OF POTENTIALLY SAVING THE PLANET.

ANOTHER WAY TO PUT A PRICE ON CARBON IS WITH  
**CAP AND TRADE.**



LIKE THE EMISSIONS  
TRADING SYSTEM  
IN EUROPE...

... OR THE GLOBAL  
WARMING SOLUTIONS  
ACT IN CALIFORNIA.

THE WAY **POLITICIANS** TALK ABOUT CAP AND TRADE CAN  
MAKE IT SOUND LIKE **MAGIC**...

WE'RE GOING TO  
CAP EMISSIONS...

... AND LET PEOPLE  
MAKE MONEY FROM  
TRADING.

WHAT'S NOT  
TO LIKE?



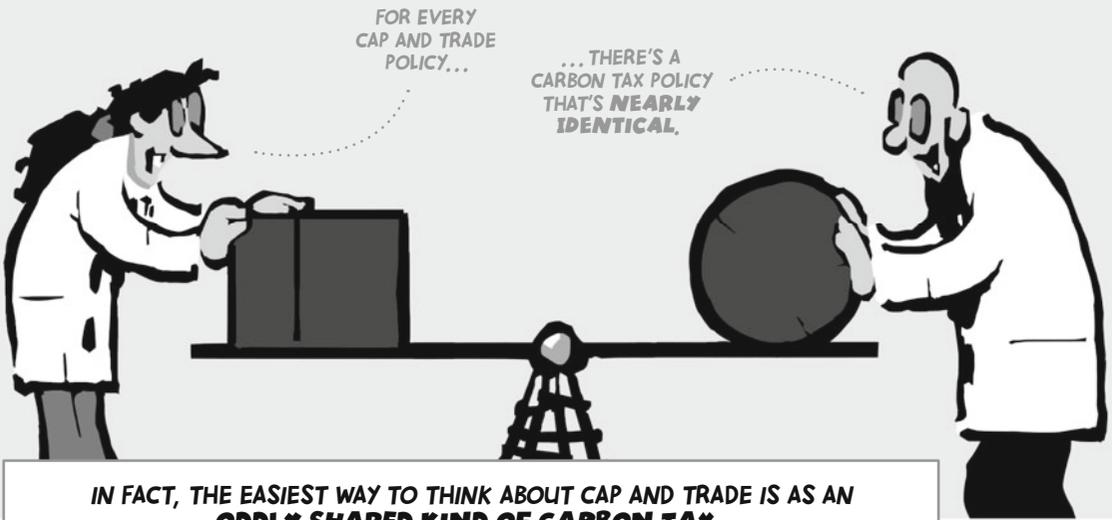
... A SPECIAL KIND OF MAGIC THAT HAS **NOTHING IN COMMON WITH TAXES.**

TAXES ARE **BAD**...

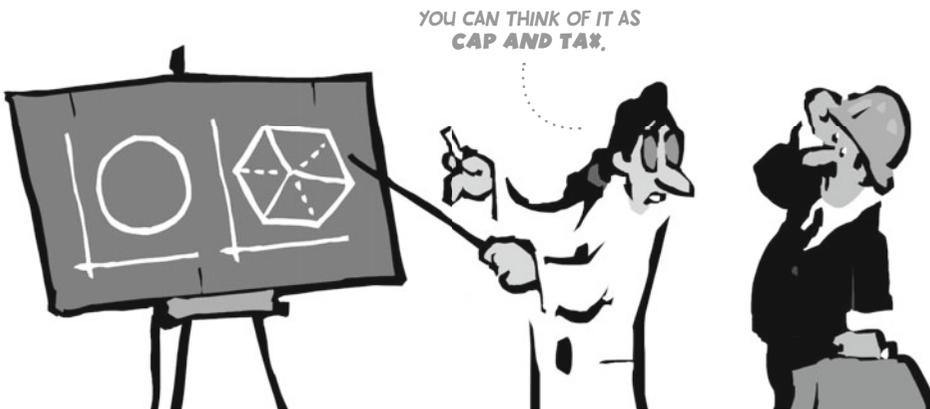
... **TRADING IS  
GOOD!**



**BUT ECONOMISTS KNOW THAT CAP AND TRADE AND CARBON TAXES ARE ACTUALLY QUITE SIMILAR.**



**IN FACT, THE EASIEST WAY TO THINK ABOUT CAP AND TRADE IS AS AN ODDLY SHAPED KIND OF CARBON TAX.**



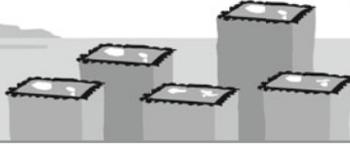
**TO UNDERSTAND THE GUTS OF CAP AND TRADE, THOUGH, A GOOD PLACE TO START IS WITH FISH.**



**TO AVOID OVERFISHING, GOVERNMENTS AROUND THE WORLD SET LIMITS ON FISHING AND THEN ISSUE PERMITS.**

THE SUSTAINABLE HARVEST LEVEL FOR THIS YEAR IS 10,000 TONS...

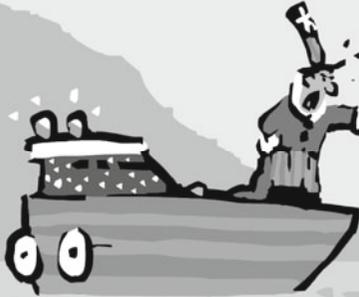
... SO LET'S PRINT UP 10,000 PERMITS AND DISTRIBUTE THEM TO FISHERMEN.



**FISHERMEN THEN HAVE TO TURN IN ONE PERMIT FOR EACH TON OF FISH THEY CATCH...**

ONE STINKIN' PERMIT PER TON...

... OTHERWISE WE'LL FEED YOU TO THE SHARKS!

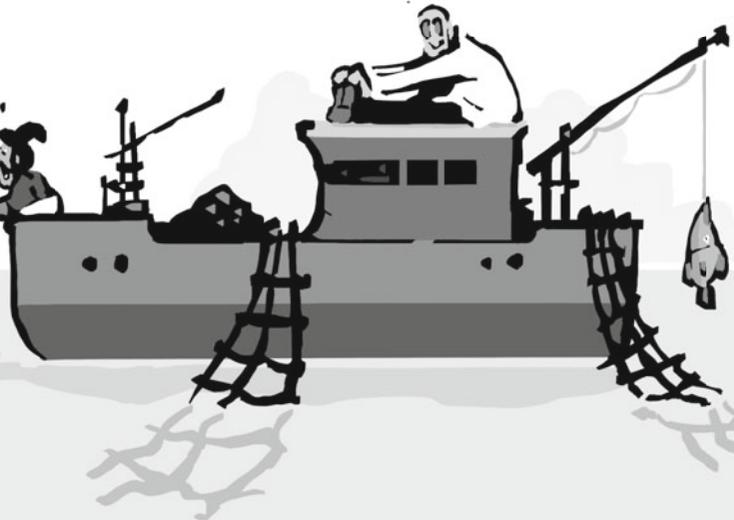


**... AND THEY CAN TRADE THE PERMITS WITH EACH OTHER.**

IF MY BOAT BREAKS, I CAN SELL MY PERMITS.

AND IF I FIND A TERRIFIC NEW FISHING SPOT, I CAN BUY EXTRA PERMITS.

THAT'S WHAT MAKES MARKET-BASED INSTRUMENTS FLEXIBLE!



**TO SEE HOW THIS APPLIES TO CLIMATE CHANGE,  
REPLACE FISH WITH CO<sub>2</sub>.**

LET'S  
TRADE CO<sub>2</sub>...  
... JUST FOR THE  
HALIBUT.

**WITH CARBON CAP AND TRADE, GOVERNMENTS  
SET LIMITS ON CO<sub>2</sub> EMISSIONS  
AND ISSUE PERMITS.**



LET'S CAP EMISSIONS AT  
100,000 TONS...

... AND DISTRIBUTE  
100,000 PERMITS  
TO POLLUTE.



**COMPANIES THEN HAVE TO TURN IN ONE PERMIT  
FOR EACH TON OF CO<sub>2</sub> THEIR PRODUCTS EMIT...**

ONE PERMIT  
PER TON...

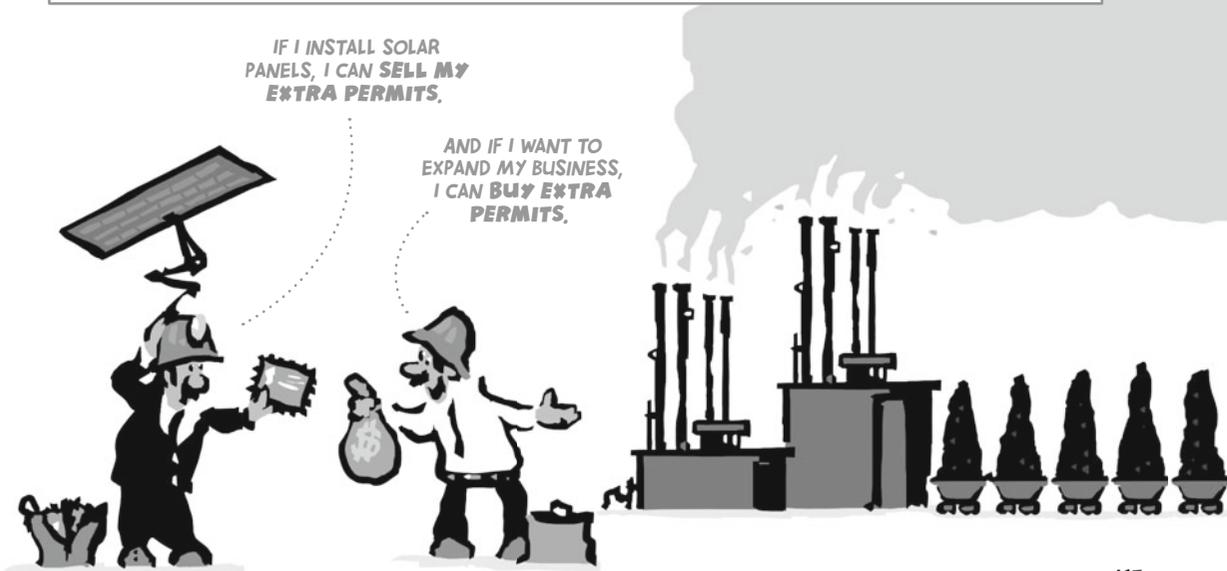
... OTHERWISE WE'LL TAKE  
A BITE OUT OF YOUR  
BOTTOM LINE.



**... AND THEY CAN TRADE THE PERMITS WITH EACH OTHER.**

IF I INSTALL SOLAR  
PANELS, I CAN SELL MY  
EXTRA PERMITS.

AND IF I WANT TO  
EXPAND MY BUSINESS,  
I CAN BUY EXTRA  
PERMITS.



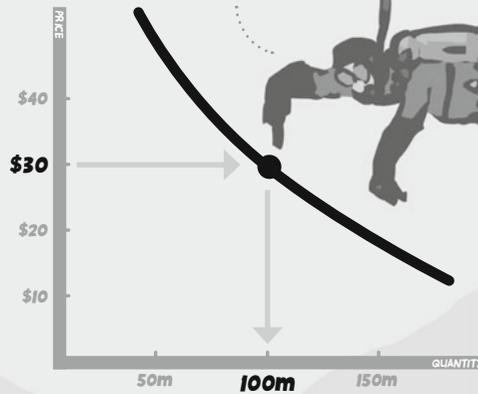
**IF YOU STUDY ENVIRONMENTAL ECONOMICS...**

LOOK, IT'S A DEMAND CURVE FOR CARBON EMISSIONS!

... YOU CAN LEARN MORE ABOUT **CARBON TAXES...**

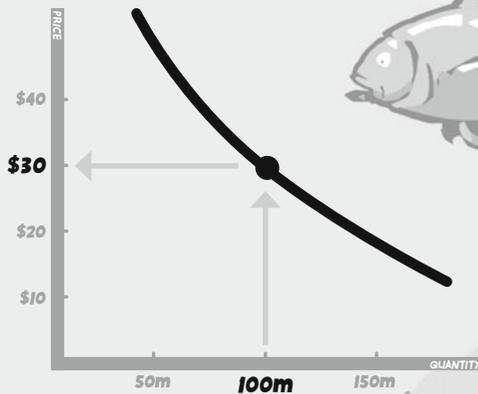
IF THE TAX IS \$30 PER TON OF CO<sub>2</sub>...

... THEN CO<sub>2</sub> EMISSIONS WOULD BE 100 MILLION TONS PER YEAR.



... AND HOW THEY COMPARE WITH **CAP AND TRADE SYSTEMS.**

YOU'LL GET A PERMIT PRICE OF \$30 PER TON...



... IF YOU CAP CO<sub>2</sub> EMISSIONS AT 100 MILLION TONS PER YEAR.

BUT IF ALL THAT GIVES YOU THE **BENDS...**



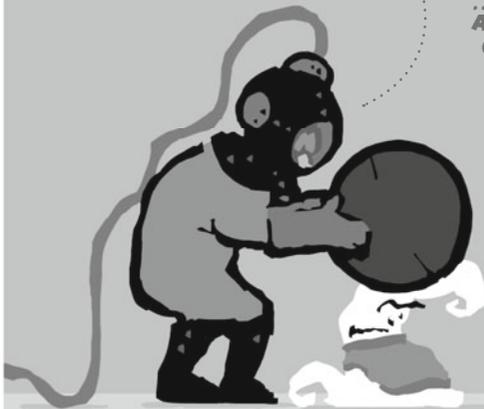
... JUST REMEMBER THAT **CARBON TAXES** AND **CAP AND TRADE SYSTEMS** ARE **DIFFERENT MEANS TO THE SAME END.**

THEY'RE BOTH **ECONOMIC INSTRUMENTS...**

JUST ABOUT ANYTHING YOU CAN DO WITH **ONE...**

... YOU CAN DO WITH **THE OTHER.**

... THAT PUT A PRICE ON CARBON.



IN PARTICULAR, A **CAP AND TRADE SYSTEM WITH AUCTIONED PERMITS...**

... GENERATES REVENUE FOR THE GOVERNMENT, JUST LIKE A **CARBON TAX.**

AND WE CAN PUT THAT REVENUE TO GOOD USE...

... FOR EXAMPLE BY **REDUCING EXISTING TAXES.**



IT'S NO SURPRISE THAT MANY **ECONOMISTS** ARE FOND OF **ECONOMIC INSTRUMENTS**...

... BUT **DIRECT REGULATIONS** ALSO HAVE SUPPORTERS.



AND WHILE THEY MIGHT DISAGREE ABOUT **POLITICS AND POLICY**...



... THEY SHARE A **COMMON GOAL**.

WE NEED TO DEVELOP A **LOW-CARBON ECONOMY**.



# CHAPTER 15

## BEYOND FOSSIL FUELS

WE NEED TO GET  
**BEYOND FOSSIL  
FUELS!**

OKAY, THERE'S  
**DEFORESTATION,  
AND METHANE,  
AND SF<sub>6</sub>, AND...**



**THE MAIN HUMAN CONTRIBUTION TO CLIMATE CHANGE COMES FROM THE CO<sub>2</sub> WE EMIT BY BURNING FOSSIL FUELS.**

NYAA!

CO<sub>2</sub>

**BUT THERE ARE OTHER HUMAN ACTIVITIES THAT ADD CO<sub>2</sub> TO THE ATMOSPHERE...**

LIKE  
**DEFORESTATION!**

**... AND THERE ARE OTHER GREENHOUSE GASES BESIDES CO<sub>2</sub>.**

MOLECULE FOR MOLECULE,  
I PRODUCE 28 TIMES MORE  
**WARMING** THAN CO<sub>2</sub>.

YEAH, WELL  
I PRODUCE  
**24,000 TIMES MORE!**

CH<sub>4</sub>

SF<sub>6</sub>

SO WHILE CO<sub>2</sub> FROM FOSSIL FUELS IS THE **KINGPIN...**



... WE ALSO NEED TO TACKLE THE **NON-FOSSIL-FUEL SOURCES** THAT WE'LL LEARN ABOUT IN THIS CHAPTER,

EVERY LITTLE BIT HELPS!

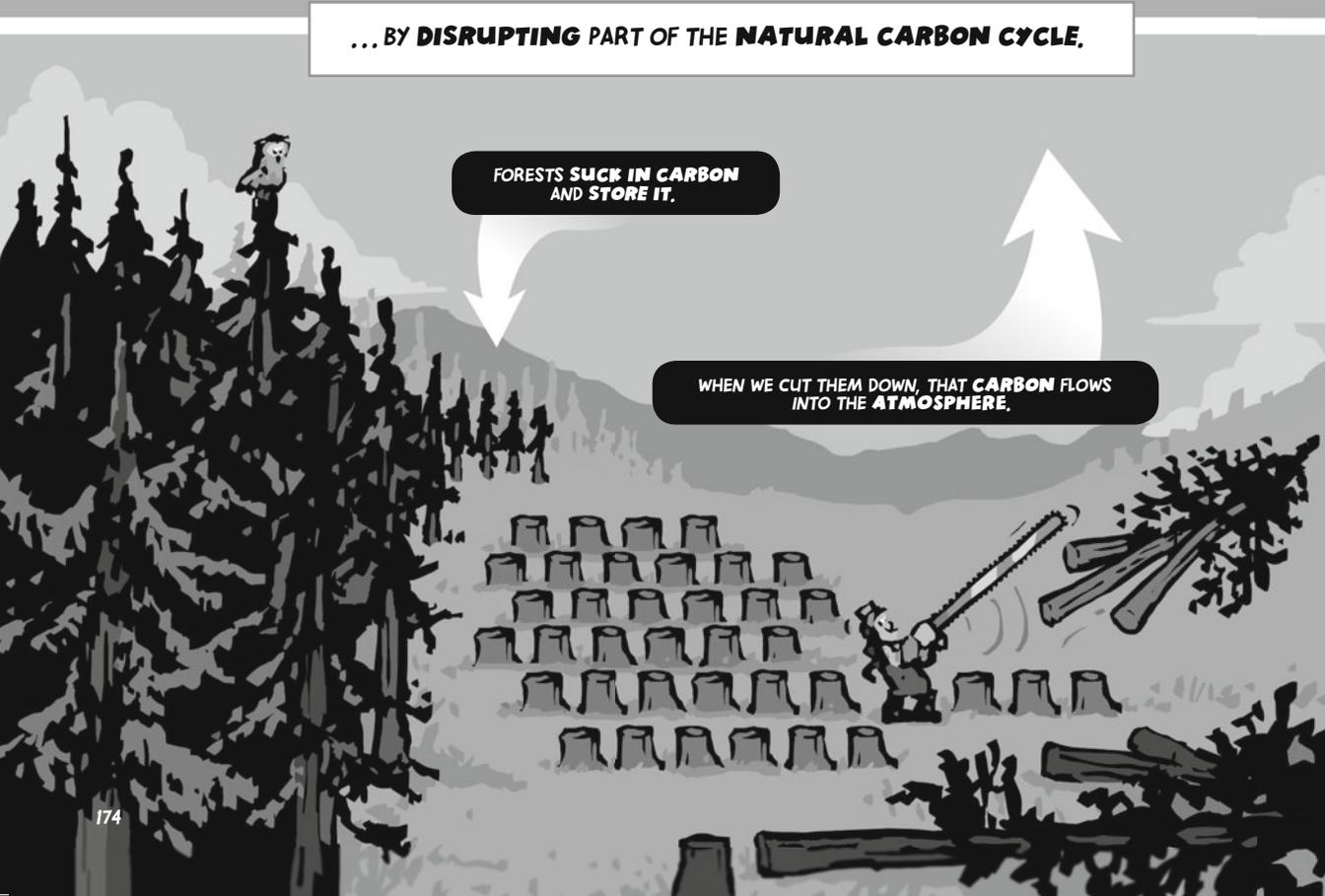
AND SOMETIMES WE CAN GET MORE BANG FOR OUR BUCK BY GOING AFTER THE **LITTLE GUYS**.





**DEFORESTATION INCREASES  
ATMOSPHERIC CO<sub>2</sub>...**

**... BY DISRUPTING PART OF THE NATURAL CARBON CYCLE.**



**FORESTS SUCK IN CARBON  
AND STORE IT.**

**WHEN WE CUT THEM DOWN, THAT CARBON FLOWS  
INTO THE ATMOSPHERE.**

NOWADAYS, DEFORESTATION MOSTLY HAPPENS IN **POOR COUNTRIES** LIKE BRAZIL, INDONESIA, AND NIGERIA...



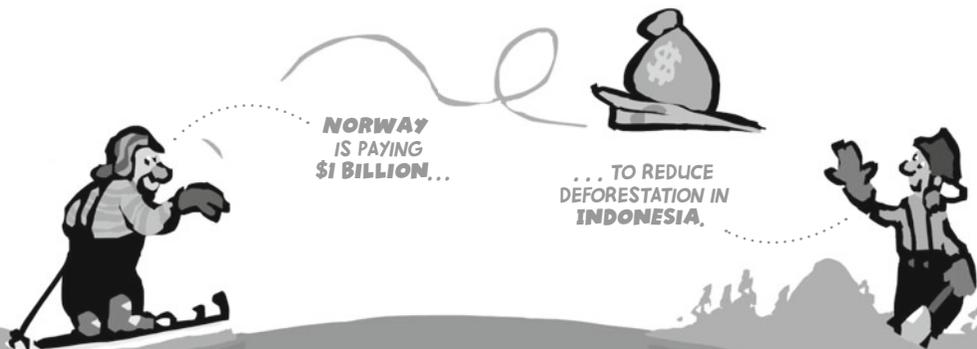
... BUT THEY'RE JUST FOLLOWING THE PATH **LAI**D DOWN BY THE RICH WORLD IN **PREVIOUS CENTURIES**.



FORTUNATELY, MANY MIDDLE- AND HIGH-INCOME COUNTRIES ARE NOW **PLANTING NEW FORESTS**...



... AND SOME RICH COUNTRIES ARE **PAYING POOR COUNTRIES** TO PRESERVE THEIR FORESTS.





**METHANE (CH<sub>4</sub>) IS THE MAIN COMPONENT OF NATURAL GAS.**



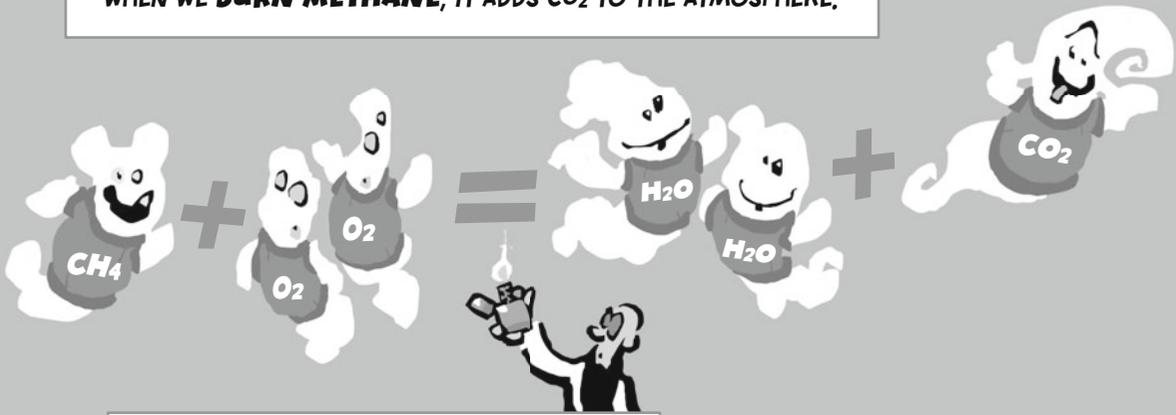
BUT IT'S NOT JUST A FOSSIL FUEL.

IT ALSO COMES FROM FARM ANIMALS...

...AND LANDFILLS ...

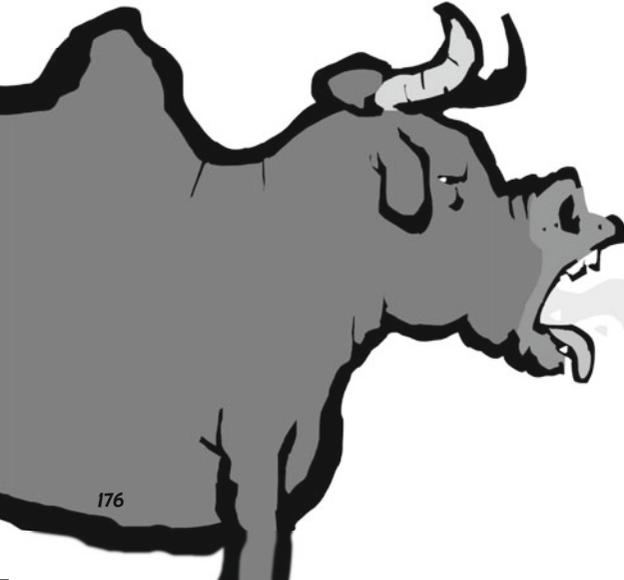
...AND RICE PADDIES.

**WHEN WE BURN METHANE, IT ADDS CO<sub>2</sub> TO THE ATMOSPHERE.**

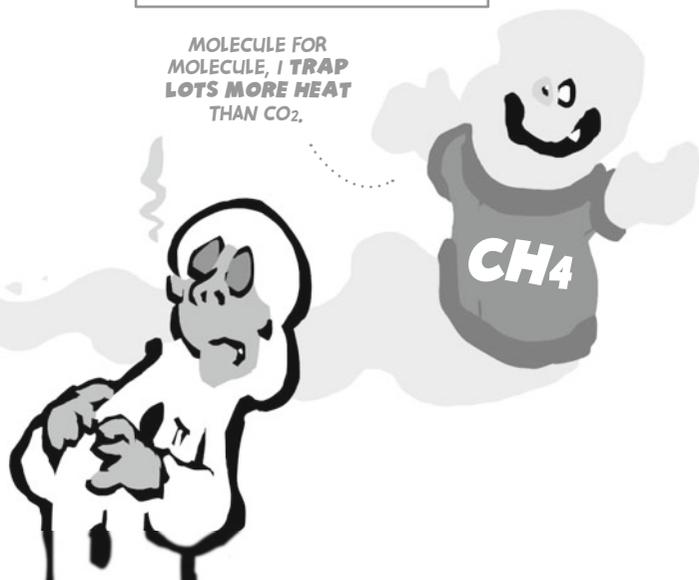


**BUT WHEN WE RELEASE METHANE INTO THE ATMOSPHERE WITHOUT BURNING IT...**

**... THAT'S EVEN WORSE.**



MOLECULE FOR MOLECULE, I TRAP LOTS MORE HEAT THAN CO<sub>2</sub>,



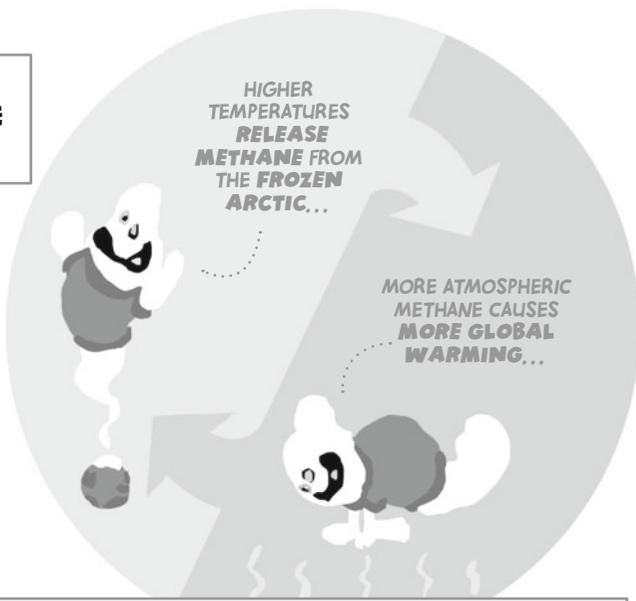
**METHANE IS A RISK BECAUSE IT CAN BE PART OF A POSITIVE FEEDBACK LOOP...**

**WARMING TURNS INTO EVEN MORE WARMING.**



**HIGHER TEMPERATURES RELEASE METHANE FROM THE FROZEN ARCTIC...**

**MORE ATMOSPHERIC METHANE CAUSES MORE GLOBAL WARMING...**



**... BUT IT'S ALSO AN OPPORTUNITY, ESPECIALLY AROUND LANDFILLS.**

**LET'S CAP THIS LANDFILL...**



**... AND CAPTURE THE METHANE THAT COMES FROM IT.**



**CAPTURING AND BURNING METHANE IS A GOOD THING...**

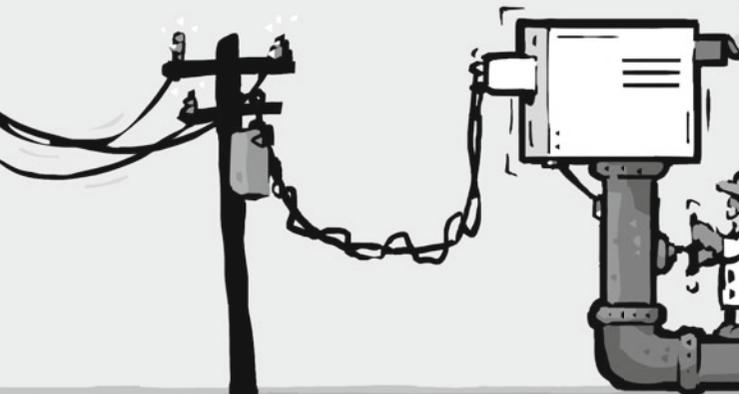


**IT'S BETTER TO BURN FUGITIVE METHANE...**

**... THAN TO ADD IT TO THE ATMOSPHERE.**

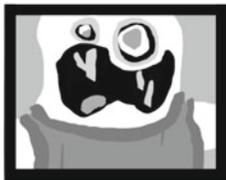


**... AND IT'S DOUBLY GOOD IF WE CAN USE THAT METHANE TO GENERATE ELECTRICITY.**



**INSTEAD OF LETTING THE METHANE ESCAPE AND BURNING COAL...**

**... WE'RE BURNING THE METHANE AND LEAVING THE COAL IN THE GROUND!**

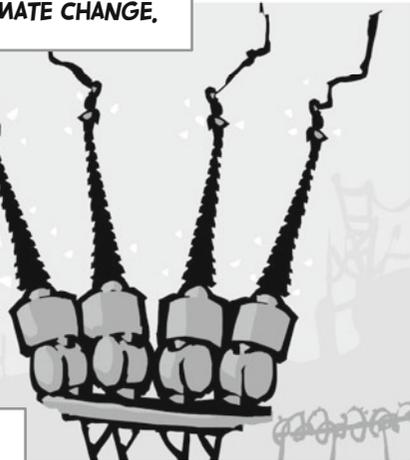


MANY **OTHER SUBSTANCES** ARE ALSO INVOLVED IN CLIMATE CHANGE.

SOME OF THEM **WARM THE PLANET.**

SF<sub>6</sub> IS AN INDUSTRIAL GAS USED IN **ELECTRICAL EQUIPMENT...**

...AND MOLECULE FOR MOLECULE IT'S **24,000 TIMES MORE POTENT THAN CO<sub>2</sub>.**



SOME OF THEM **COOL THE PLANET.**

LIKE THE **SULFUR AEROSOLS** FROM VOLCANIC ERUPTIONS,

HENCE THE **GARDEN HOSE** IDEA ON PAGE 146.

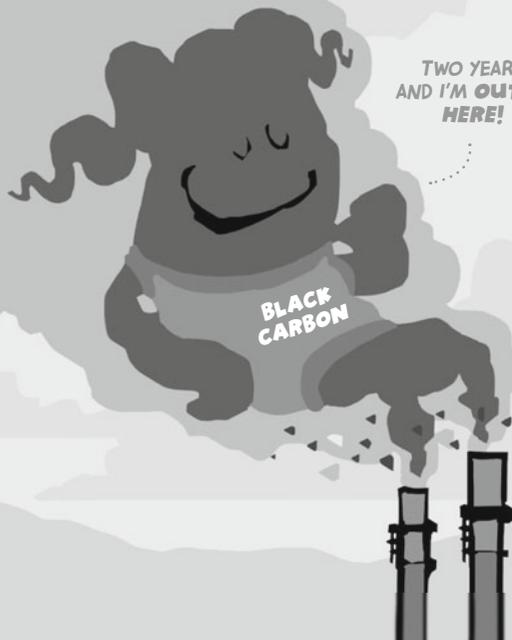


SOME OF THEM ARE **SHORT LIVED.**

SOME OF THEM ARE **LONG LIVED.**

TWO YEARS AND I'M **OUTTA HERE!**

I'M GOING TO HAUNT YOU **FOREVER.**



THESE **PETTY CRIMINALS** ARE NOT AS IMPORTANT AS THE **BIG THREE** ...

THAT'S METHANE...

... CO<sub>2</sub> FROM DEFÖRESTRATION...

... AND CO<sub>2</sub> FROM FOSSIL FUELS.



... BUT WE SHOULD STILL TRY TO **GET THEM UNDER CONTROL**.

**RAID!**



ONE WAY TO DO THAT IS WORTH DISCUSSING IN **MORE DETAIL**.



YOU MAY HAVE ENCOUNTERED **OFFSETS** IN THE CONTEXT OF YOUR OWN PERSONAL **CARBON FOOTPRINT**.



IF I **BUY OFFSETS** THEN SOMEBODY WILL **PLANT TREES...**



... SO THAT I CAN **FLY AROUND THE WORLD...**



... AND LIVE IN A **MANSION...**

... **GUILT-FREE!**



BUT **OFFSETS** ARE ALSO USED IN MANY **CAP AND TRADE** SYSTEMS.

INSTEAD OF **BUYING EXTRA EMISSIONS PERMITS** FOR MY **FACTORY...**

... I'M GOING TO **BUY OFFSETS** SO SOMEBODY WILL **CAP LANDFILLS...**

... OR **REDUCE CO2 EMISSIONS** IN **CHINA** OR **INDIA**.



**THE THEORY BEHIND OFFSETS MAKES GOOD SENSE...**

**I REALLY WANT TO GO TO HAWAII...**

... SO I'D HAPPILY PAY SOMEONE \$50 TO PLANT ENOUGH TREES TO OFFSET MY CO<sub>2</sub> EMISSIONS.



**CUTTING EMISSIONS IS CHEAPER IN A CHINESE FACTORY THAN IN MY FACTORY AT HOME...**

... SO OFFSETS GENERATE MORE EMISSIONS REDUCTIONS PER DOLLAR.



**... BUT THE DEVIL IS IN THE DETAILS.**

**HOW DO YOU KNOW THOSE TREES ARE ACTUALLY GOING TO GET PLANTED?**

**AND WHAT IF THEY GET PAVED OVER NEXT YEAR?**



**HOW DO YOU KNOW THAT CHINESE FACTORY IS REALLY GOING TO CUT ITS EMISSIONS?**

**AND WHAT IF IT GETS REPLACED NEXT YEAR WITH A DIRTY FACTORY ELSEWHERE?**

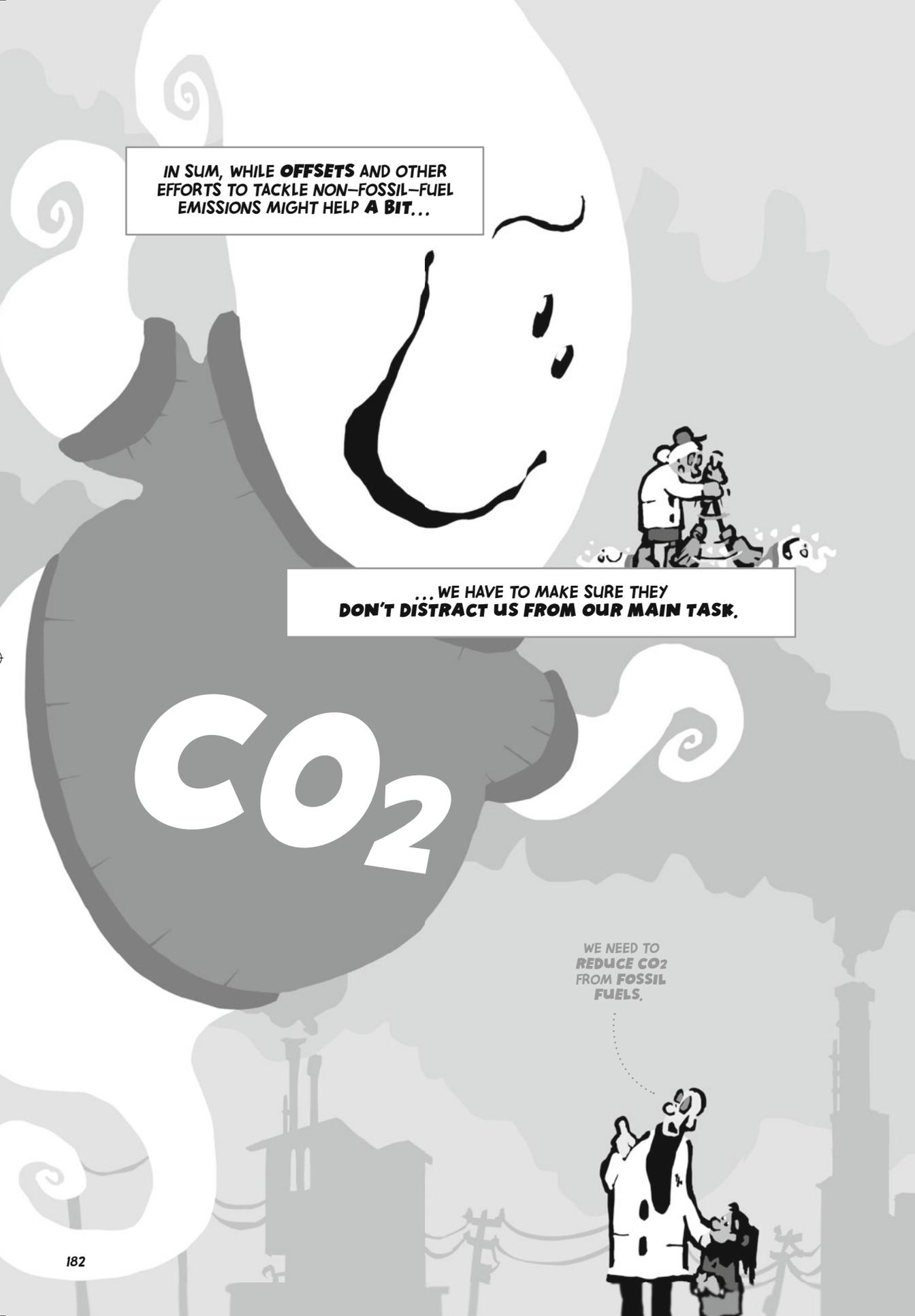


**AND WHAT ABOUT SCAMS?**

**HEY BUDDY, WANNA BUY SOME FOREST OFFSETS?**

**HEY BUDDY, WANNA BUY SOME FACTORY OFFSETS?**





IN SUM, WHILE **OFFSETS** AND OTHER EFFORTS TO TACKLE NON-FOSSIL-FUEL EMISSIONS MIGHT HELP **A BIT...**



... WE HAVE TO MAKE SURE THEY **DON'T DISTRACT US FROM OUR MAIN TASK.**

**CO<sub>2</sub>**

WE NEED TO **REDUCE CO<sub>2</sub>** FROM **FOSSIL FUELS.**



# CHAPTER 16

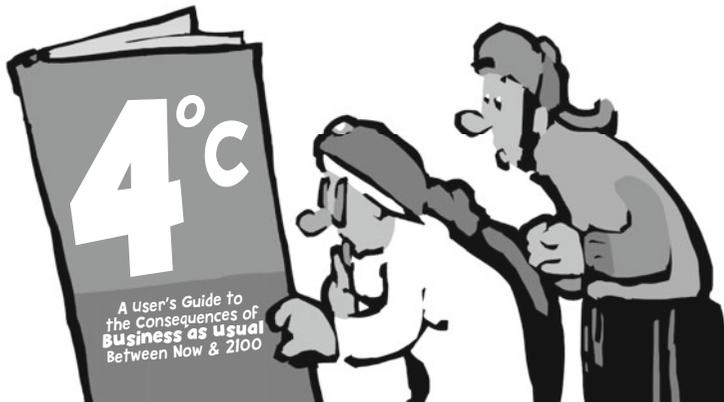
## THE CHALLENGE



IN THIS BOOK WE'VE STUDIED  
THE **SCIENCE** OF CLIMATE CHANGE...



...AND GLIMPSED THE **FUTURE** WE'RE LIKELY TO FACE  
UNDER **BUSINESS AS USUAL**...



...AND SEEN WHAT WE CAN DO TO CREATE A **DIFFERENT FUTURE**.



WE DON'T HAVE TO  
JUST SUFFER.

WE CAN  
MITIGATE AND  
ADAPT.

FOR OUR CONCLUSION, LET'S STEP BACK  
AND LOOK AT THE **BIG PICTURE...**



... BY THINKING ABOUT  
THE SIMILARITIES BETWEEN  
**PLANET EARTH...**

... AND A **COMPOST HEAP.**

A COMPOST  
HEAP?



A PROPERLY MAINTAINED **COMPOST HEAP** CONTAINS  
A HOST OF **MICRO-ORGANISMS**.

WHAT DO YOU CALL  
A SINGLE-CELLED  
ORGANISM IN A PILE  
OF LEAVES?

**RUSSELL.**



WHAT DO YOU CALL  
A SINGLE-CELLED  
ORGANISM IN A CLUMP  
OF DIRT?

**CLAUDE.**



WHAT DO YOU CALL  
A SINGLE-CELLED  
ORGANISM **WHO'S**  
GARDENING?

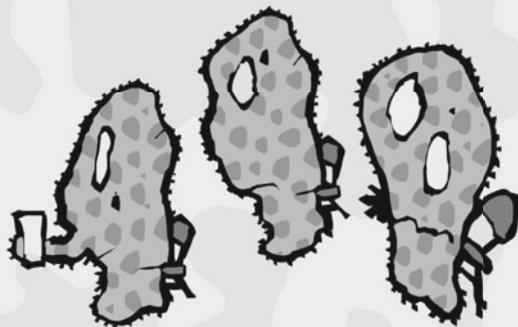
**NEIL.**

THOSE MICRO-ORGANISMS  
**BREAK DOWN LEAVES AND FOOD WASTE...**



HERE AT  
**OPEN-MIC**  
NIGHT...

...IT'S NOT JUST  
**OLD JOKES** THAT  
GET RECYCLED.

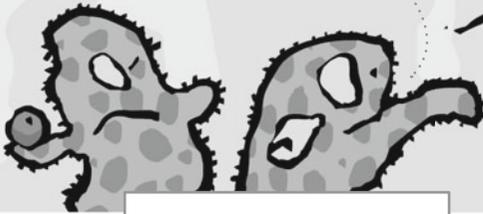


...AND TURN **GARBAGE INTO GOLD.**



**EUREKA!**  
IT'S **FERTILIZER!**

BUT AS THOSE  
MICRO-ORGANISMS EAT...

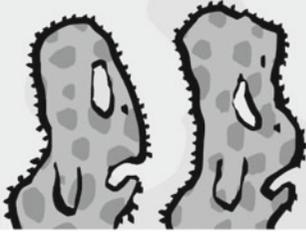


YOUR JOKES  
STINK!

YUM!  
I LOVE ROTTEN  
TOMATOES!



... AND REPRODUCE...



HEY, AT LEAST  
I'M CRACKING  
MYSELF UP.



... THEY ALSO GENERATE HEAT.



PARTY  
ON!



IN FACT, WITHOUT PROPER MAINTENANCE,  
A COMPOST PILE WILL GET  
**HOTTER AND HOTTER...**

IT'S NOT  
RED HOT...

... IT'S INFRARED  
HOT!



... UNTIL THE MICRO-ORGANISMS  
LITERALLY **KILL THEMSELVES OFF.**



TOO BAD WE NEVER  
LEARNED ABOUT THE  
TRAGEDY OF THE  
COMMONS!



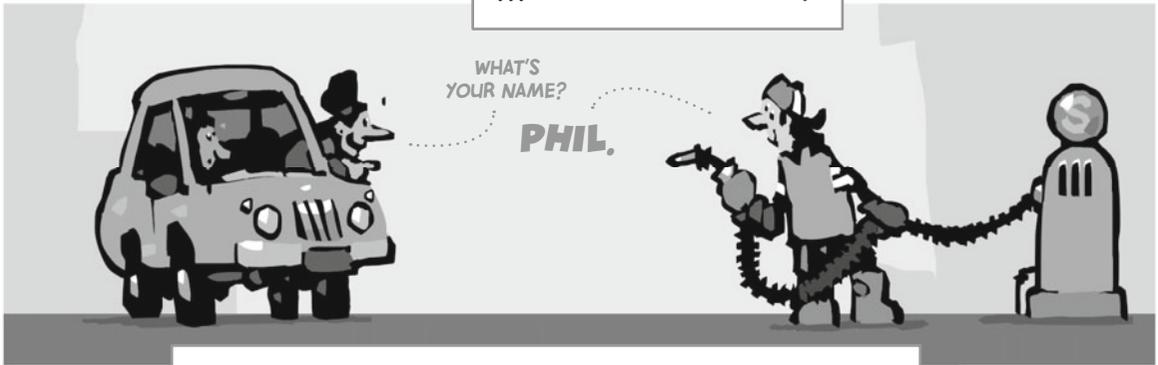
**SIMILARLY, PLANET EARTH  
CONTAINS A HOST OF PEOPLE  
EATING...**



**... AND REPRODUCING...**



**... AND GENERATING HEAT.**



**JUST LIKE MICRO-ORGANISMS WARMING A COMPOST PILE,  
WE'RE WARMING THE PLANET.**

**IN THE CASE  
OF MICROBES, IT'S  
WASTE ENERGY.**

**IN THE CASE OF  
HUMANS, IT'S  
EMISSIONS OF  
GREENHOUSE  
GASES.**



FORTUNATELY, **UNLIKE** THE MICRO-ORGANISMS, WE'VE GOT SOME **SECRET WEAPONS.**

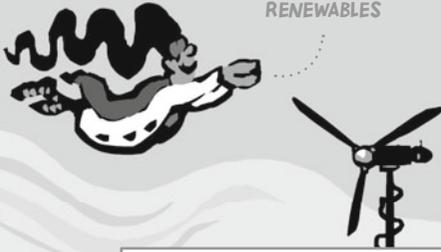
IF WE ONLY HAD **BRAINS!**



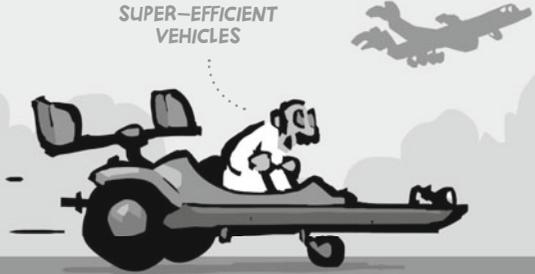
WE HAVE SMART SCIENTISTS INVENTING **NEW TECHNOLOGIES.**



NEXT-GENERATION RENEWABLES



SUPER-EFFICIENT VEHICLES



WE HAVE GOOD **POLICY IDEAS** TO GUIDE OUR WAY.



AND WE HAVE THE ABILITY TO **LOOK AHEAD** AND MAKE **SMART CHOICES** ABOUT THE FUTURE.

BUSINESS AS USUAL ONLY GOT **ONE STAR** IN OUR GUIDEBOOK.



MAKE NO MISTAKE, THOUGH:  
OUR TASK IS **DAUNTING**.

HAVING **SECRET WEAPONS** DOESN'T GUARANTEE YOU'RE GOING TO **WIN**.



AS WITH THE MICRO-ORGANISMS, THE AMOUNT OF WARMING CAUSED BY HUMANS IS RELATED TO **POPULATION**...



THE HUMAN POPULATION IS LIKELY TO INCREASE BY OVER **50%** THIS CENTURY.

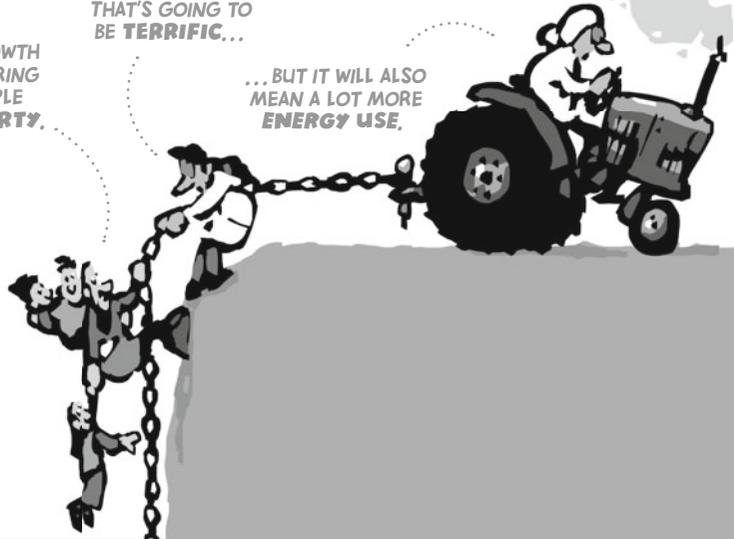


...AND TO **ACTIVITY LEVELS**.

ECONOMIC GROWTH IS GOING TO BRING A LOT OF PEOPLE **OUT OF POVERTY**.

THAT'S GOING TO BE **TERRIFIC**...

...BUT IT WILL ALSO MEAN A LOT MORE **ENERGY USE**.



THAT'S WHY **BU**SINESS AS USUAL COULD RESULT IN A **TRIPLING** OF ANNUAL CO<sub>2</sub> EMISSIONS THIS CENTURY.

IT WILL TAKE **TREMENDOUS EFFORT** JUST TO KEEP ANNUAL EMISSIONS STEADY.

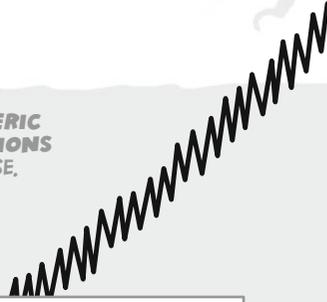


AND REMEMBER THAT CO<sub>2</sub> STAYS IN THE ATMOSPHERE FOR A **LONG, LONG TIME...**



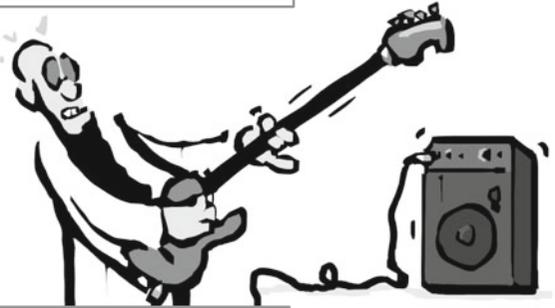
SO EVEN IF WE DO KEEP CO<sub>2</sub> EMISSIONS **STEADY...**

... **ATMOSPHERIC CONCENTRATIONS** WILL STILL RISE.



... AND THAT THE PROBLEM IS COMPOUNDED BY **DEFORESTATION...**

... AND **FEEDBACKS...**



... AND THAT ANY SOLUTIONS WILL HAVE TO **OVERCOME THE TRAGEDY OF THE COMMONS.**



THEY WEREN'T KIDDING: THE TASK IS **DAUNTING.**



**BUT DAUNTING DOESN'T MEAN IMPOSSIBLE!**



OK, BUT WHAT CAN **WE** DO?

YOU CAN HELP BY **DREAMING**  
OF A BETTER FUTURE...

I SEE A  
PRINCESS.

I SEE A  
DRAGON.

I SEE A  
SOLUTION  
TO CLIMATE  
CHANGE!



... AND THEN FIGURING OUT WHETHER  
THAT **DREAM** COULD REALLY **COME TRUE**...



... AND THEN WORKING TO **MAKE IT HAPPEN**.

OKAY, IT'S  
READY TO  
GO.

TIME TO  
CHANGE THE  
WORLD!

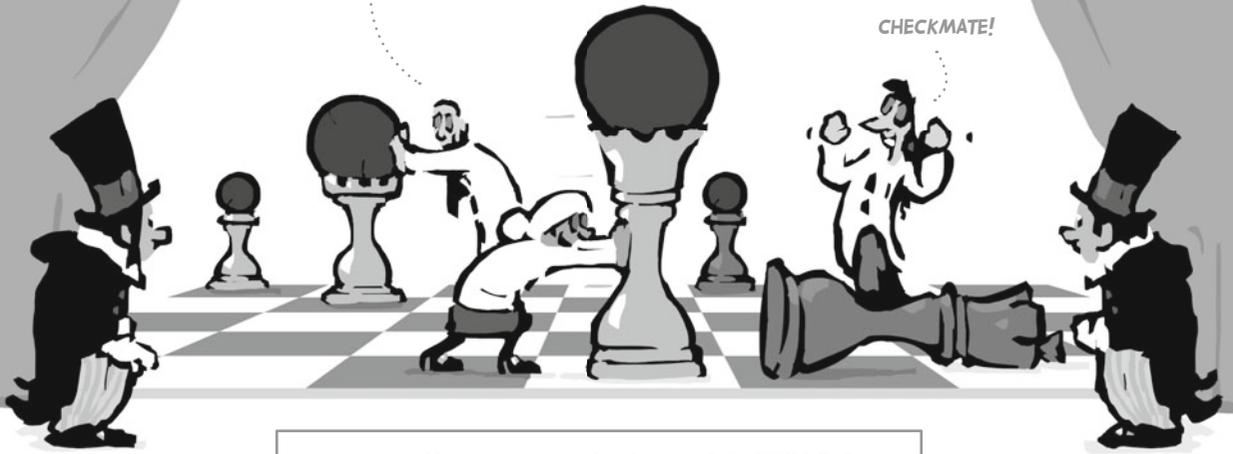


AS YOU KNOW, LOTS OF ECONOMISTS DREAM OF **CARBON PRICING**...

IF THE RICH WORLD  
ADOPTS **REVENUE-  
NEUTRAL CARBON  
TAXES**...

... THEN THE **POWER  
OF CAPITALISM**  
COULD BRING US...

... **CHEAP, CLEAN  
ENERGY** TO POWER  
THE WHOLE WORLD.



... BUT IT'S OKAY IF YOUR DREAM IS **DIFFERENT**.

**ALL-OUT MOBILIZATION**

WE NEED A **WAR**  
ON CARBON  
EMISSIONS.



**GOVERNMENT-FUNDED CLEAN  
ENERGY RESEARCH**

WE NEED A  
**BREAKTHROUGH**.



**PLANNING AND ADAPTATION**

WE NEED TO  
**PREPARE**.



**LOW-CARBON LIFESTYLES**

WE NEED TO **LIVE  
SIMPLY** SO THAT OTHERS  
CAN **SIMPLY LIVE**.

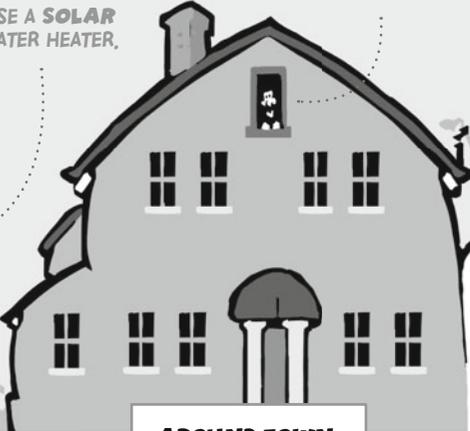


**YOU CAN ALSO HELP BY LOOKING AT YOUR OWN LIFE...**

**AT HOME,**



USE A **SOLAR** WATER HEATER.



MAKE SURE YOUR HOUSE IS **WELL-INSULATED**.

THINK HARD ABOUT HOW MUCH **SPACE** YOU NEED.

USE **MORE-EFFICIENT** LIGHTS AND APPLIANCES.



**AROUND TOWN,**

**REDUCE, REUSE, RECYCLE.**



THINK HARD ABOUT HOW MUCH **STUFF** YOU NEED TO BUY.

**EAT MORE** VEGETABLES.

**EAT LESS** MEAT.



**ON THE ROAD,**

**DON'T SPEED...**

...AND KEEP YOUR TIRES **INFLATED.**



THINK HARD ABOUT HOW MUCH YOU **FLY.**



HAVE **MORE** LOW-CARBON ADVENTURES.

**DRIVE LESS.**



... AND BY HELPING YOUR COMMUNITY AND YOUR COUNTRY  
**MAKE SMART DECISIONS.**

USE YOUR **VOICE**.



EXCUSE ME,  
REPRESENTATIVE...



JOIN A **CHORUS**.



INVITE OTHERS TO **JOIN YOU**.

WHEN YOU'RE DONE  
WITH THIS BOOK, GIVE  
IT TO A **FRIEND** OR A  
**NEIGHBOR...**

... OR AN  
**ELECTED  
OFFICIAL.**

IN WAYS BIG AND SMALL, **YOU** CAN HELP WRITE THE NEXT CHAPTER.



THAT NEXT CHAPTER IS BEING  
WRITTEN **NOW**.

GOOD LUCK  
TO US **ALL**.



# GLOSSARY

## A

### **ADAPTATION**

EFFORTS TO REDUCE THE IMPACT OF CLIMATE CHANGE, SUCH AS BUILDING SEAWALLS OR DESIGNING DROUGHT-RESISTANT FARMING PRACTICES; CONTRAST WITH **MITIGATION**: 102, 105–10, 184

### **AIR**

MEASURED IN TERMS OF THE PERCENTAGES OF DIFFERENT TYPES OF MOLECULES, THE ATMOSPHERE IS ABOUT 78% NITROGEN ( $N_2$ ), 21% OXYGEN ( $O_2$ ), AND 1% OTHER, INCLUDING ABOUT 0.04% CARBON DIOXIDE ( $CO_2$ ), WHICH EQUALS 400 PARTS PER MILLION (ppm)  $CO_2$ : 40

### **ALBEDO**

THE REFLECTIVITY OF A SUBSTANCE; THE EARTH'S ALBEDO IS ABOUT 30%. TO REMEMBER ITS MEANING, NOTE THAT "ALBEDO" ("WHITENESS") HAS THE SAME LATIN ROOT AS "ALBINO": 56, 146

THE **ICE-ALBEDO EFFECT** IS A POSITIVE FEEDBACK LOOP THAT CONTRIBUTES TO THE COMINGS AND GOINGS OF ICE AGES: IN THE GLACIAL DIRECTION, ACCUMULATING ICE AND SNOW INCREASES THE ALBEDO OF THE EARTH'S SURFACE, RESULTING IN DECREASED SOLAR ABSORPTION THAT LOWERS TEMPERATURES AND LEADS TO MORE ACCUMULATION OF ICE AND SNOW; IN THE INTERGLACIAL DIRECTION, MELTING ICE AND SNOW REDUCES THE ALBEDO OF THE EARTH'S SURFACE, RESULTING IN INCREASED SOLAR ABSORPTION THAT RAISES TEMPERATURES AND LEADS TO MORE MELTING ICE AND SNOW: 35, 37, 126

### **ANTHROPOGENIC**

CAUSED BY HUMANS: 70–72

### **ARCTIC**

THE REGION AROUND THE NORTH POLE; MOST **ARCTIC ICE** IS FLOATING, AND SO MELTING DOES NOT CONTRIBUTE TO SEA LEVEL RISE (UNLIKE THE MOSTLY LAND-BASED **ANTARCTIC ICE** AROUND THE SOUTH POLE): 86, 94, 124

### **ARRHENIUS, SVANTE**

A SWEDISH CHEMIST, SVANTE ARRHENIUS (1859–1927) WAS ONE OF THE FIRST SCIENTISTS TO STUDY ATMOSPHERIC  $CO_2$ : 62, 119



B

**BLACK CARBON**

AIRBORNE PARTICLES SUCH AS SOOT, MOST COMMONLY FORMED FROM BURNING PLANT MATTER OR FOSSIL FUELS: 178



**BORDER TAX ADJUSTMENT**

A TAX THAT COULD BE APPLIED (AT LEAST IN THEORY) TO THE CARBON "EMBODIED" IN IMPORTED GOODS; FOR EXAMPLE, IF COUNTRY A HAS A CARBON TAX BUT COUNTRY B DOESN'T, COUNTRY A COULD TAX GOODS IMPORTED FROM COUNTRY B: 144

**BUSINESS AS USUAL**

A HYPOTHETICAL FUTURE FEATURING MINIMAL EFFORTS TO REDUCE CARBON EMISSIONS AND STRONG ECONOMIC GROWTH BASED ON FOSSIL FUELS; FOR EXAMPLE, SEE THE IPCC SCENARIO KNOWN AS RCP 8.5: 79–82, 128–29, 189



C

**CAP AND TRADE**

SEE **CARBON PRICING**



**CARBON (C)**

ONE OF THE BUILDING BLOCKS OF LIFE ON EARTH, BURNING PLANTS AND FOSSIL FUELS TURNS THE CARBON THEY CONTAIN INTO CARBON DIOXIDE (CO<sub>2</sub>), WHICH IS A GREENHOUSE GAS. THE **CARBON CYCLE** DESCRIBES HOW CARBON CIRCULATES AROUND THE PLANET AND INCLUDES NOT ONLY BURNING OF PLANTS AND FOSSIL FUELS BUT ALSO PROCESSES SUCH AS PHOTOSYNTHESIS; AIR–OCEAN GAS EXCHANGE, WHICH IS RELATED TO OCEAN ACIDIFICATION; THE CREATION AND WEATHERING OF ROCKS, ETC.

CARBON CYCLE: 18, 42–43, 47

CARBON DIOXIDE (CO<sub>2</sub>): 17, 21, 39–50, 114, 191

CARBON SINK: 46, 146

CARBON VERSUS CO<sub>2</sub>: 44 (SEE ALSO **CARBON VERSUS CO<sub>2</sub>**)

**CARBON PRICING**

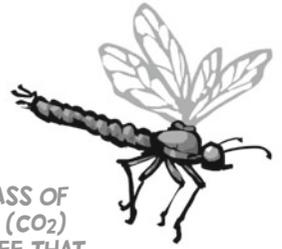
A GOVERNMENT POLICY THAT SEEKS TO REDUCE CARBON EMISSIONS BY MAKING POLLUTING EXPENSIVE: 143–44, 159–70, 189, 193

THE SIMPLEST FORM OF CARBON PRICING IS A **CARBON TAX** ON THE CARBON CONTENT OF FOSSIL FUELS: 162–63

THE OTHER FORM OF CARBON PRICING IS **CAP AND TRADE**, A POLICY THAT REQUIRES POLLUTERS TO TURN IN ONE PERMIT FOR EACH TON OF CO<sub>2</sub> THEY EMIT; THE NUMBER OF PERMITS IS LIMITED (RAISING OR LOWERING THIS "CAP" MAKES THE POLICY LESS OR MORE STRICT) AND PERMITS CAN BE TRADED BASED ON SUPPLY AND DEMAND: 164–67, 180–81

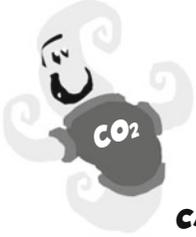
**CAUTIONARY NOTE:** A CARBON PRICE OF (SAY) \$30 PER TON OF **CARBON** IS VERY DIFFERENT FROM A CARBON PRICE OF \$30 PER TON OF **CARBON DIOXIDE** (SEE BELOW) SO IT'S IMPORTANT TO CLEARLY IDENTIFY WHICH OF THESE IS BEING DISCUSSED. PRICES ARE MOST COMMONLY GIVEN PER TON OF CARBON DIOXIDE, SO AN UNCLEAR REFERENCE TO "A TAX OF \$30 PER TON" PROBABLY MEANS \$30 PER TON OF CARBON DIOXIDE.





## CARBON VERSUS CO<sub>2</sub>

A COMMON SOURCE OF CONFUSION, CARBON (C) CONTAINS 6 PROTONS AND 6 NEUTRONS, FOR AN ATOMIC MASS OF 12. THE ATOMIC MASS OF OXYGEN IS 16, SO CARBON DIOXIDE (CO<sub>2</sub>) HAS A MOLECULAR MASS OF 44. PUT THESE TOGETHER TO SEE THAT X TONS OF CO<sub>2</sub> CONTAINS ONLY  $12x/44 \approx 0.27x$  TONS OF CARBON. SIMILARLY, BURNING X TONS OF CARBON CREATES  $44x/12 \approx 3.67x$  TONS OF CO<sub>2</sub>. AS A RESULT, A CARBON PRICE OF \$x PER TON OF CARBON EQUALS ONLY  $\$12x/44 \approx \$0.27x$  PER TON OF CO<sub>2</sub>. (CARBON PRICES ARE USUALLY STATED PER TON OF CO<sub>2</sub>, AND IN MOST CASES THE TONS ARE METRIC TONS, NOT SHORT TONS.)



## CARBONIFEROUS PERIOD

THE TIME PERIOD FROM 360–300 MILLION YEARS AGO: 23

## CATCH-UP

THE IDEA—ALSO CALLED **CONVERGENCE**—THAT POOR COUNTRIES WILL HAVE FASTER ECONOMIC GROWTH THAN RICH COUNTRIES, CAUSING THEIR ECONOMIES TO CATCH UP: 4–6, 81, 110

## CFCS

PREVIOUSLY USED IN AEROSOL CONTAINERS AND AS REFRIGERANTS, CHLOROFLUOROCARBONS (CFCS) DAMAGE THE OZONE LAYER AND ARE BEING PHASED OUT: 21

## CH<sub>4</sub> (METHANE)

SEE **GREENHOUSE GAS**

## CLEAN ENERGY

IN THE CONTEXT OF CLIMATE CHANGE, CLEAN ENERGY IS ENERGY THAT DOESN'T (OR DOESN'T MUCH) INCREASE ATMOSPHERIC CO<sub>2</sub> CONCENTRATIONS; THIS INCLUDES RENEWABLE ENERGIES SUCH AS HYDROPOWER, WIND, AND SOLAR, PLUS NUCLEAR POWER, CCS (CARBON CAPTURE AND STORAGE), AND ENERGY EFFICIENCY: 150



## CLIMATE

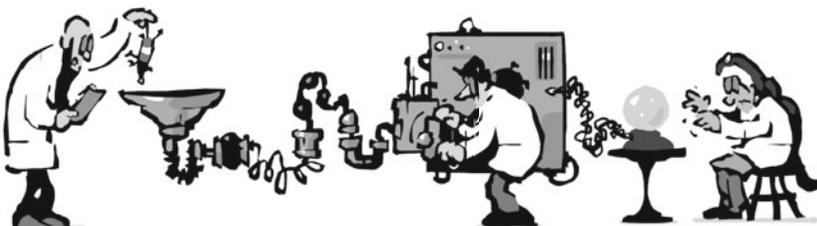
AVERAGE WEATHER, TYPICALLY OVER 30-YEAR PERIODS, INCLUDING AVERAGE VALUES AND EXPECTED VARIABILITY FOR DAILY HIGH AND LOW TEMPERATURES, PRECIPITATION, ETC.: 12

## CLIMATE CHANGE

A CHANGE IN GLOBAL AVERAGE TEMPERATURE AND OTHER CHANGES IN THE EARTH SYSTEM, EITHER AS A RESULT OF NATURAL PROCESSES OR (AS WITH **ANTHROPOGENIC CLIMATE CHANGE**) AS A RESULT OF BURNING FOSSIL FUELS AND OTHER HUMAN ACTIVITIES: 12

## CLIMATE MODELS

COMPUTER MODELS OF THE EARTH'S CLIMATE SYSTEM: 74





### **DEFORESTATION**

CUTTING DOWN TREES FOR FARMING, URBAN DEVELOPMENT, OR OTHER HUMAN ACTIVITIES: 10, 46, 172, 174–75, 191

### **DEVELOPED/DEVELOPING COUNTRIES**

THE DIVIDING LINE CAN BE BLURRY (SEE **CATCH-UP**), BUT THE DEVELOPED WORLD INCLUDES NORTH AMERICA, EUROPE, JAPAN, AND OTHER RICH COUNTRIES; TOGETHER THEY ACCOUNT FOR ONE-FIFTH OF THE WORLD'S POPULATION. THE DEVELOPING WORLD INCLUDES MUCH OF ASIA, AFRICA, AND SOUTH AMERICA: 4–6, 79, 107–110, 175, 190

## **E**

### **EL NIÑO**

A WEATHER PATTERN IN THE TROPICAL PACIFIC OCEAN THAT AFFECTS GLOBAL TEMPERATURE AND PRECIPITATION: 72

### **ELECTROMAGNETIC RADIATION**

A FORM OF ENERGY THAT INCLUDES VISIBLE LIGHT, LONGER-WAVELENGTH INFRARED RADIATION, AND SHORTER-WAVELENGTH ULTRAVIOLET RADIATION: 55–57

INFRARED (IR): 55, 57, 187  
ULTRAVIOLET (UV): 20, 55  
VISIBLE: 55



### **ENERGY IN/ENERGY OUT**

THE CRUCIAL DETERMINANTS OF ENERGY BALANCE FOR THE PLANET. FOR EXAMPLE, IF ENERGY IN IS LARGER THAN ENERGY OUT THEN THE PLANET WILL WARM UP: 51–59

### **EVOLUTION**

THE PROCESS BY WHICH MUTATION AND NATURAL SELECTION LEADS TO THE CREATION OF NEW SPECIES: 24, 104–105



### **EXTERNAL COST**

COSTS IMPOSED ON A THIRD PARTY, FOR EXAMPLE IF PERSON A SELLS COAL-FIRED ELECTRICITY TO PERSON B BUT BURNING THE COAL HARMS PERSON C'S HEALTH OR PROPERTY: 155

## **F**

### **FEEDBACK**

A SECONDARY EFFECT THAT EITHER AMPLIFIES OR WEAKENS SOME INITIAL CHANGE. A **POSITIVE FEEDBACK LOOP** AMPLIFIES THE INITIAL CHANGE, SO THAT WARMING TURNS INTO EVEN MORE WARMING OR COOLING TURNS INTO EVEN MORE COOLING. A **NEGATIVE FEEDBACK LOOP** WEAKENS THE INITIAL CHANGE, SO THAT WARMING TURNS INTO A BIT LESS WARMING AND COOLING TURNS INTO A BIT LESS COOLING: 32–33, 35, 37, 96, 126, 177, 191

ICE-ALBEDO FEEDBACK: 35, 37, 126  
WATER VAPOR FEEDBACK: 96, 126

### **FINGERPRINTS**

TELLTALE SIGNS CONNECTING HUMAN EMISSIONS OF GREENHOUSE GASES TO CLIMATE CHANGE: 70–71



## FISHERIES

A COMMON EXAMPLE OF THE **TRAGEDY OF THE COMMONS** AND OF THE USE OF CAP AND TRADE SYSTEMS TO ADDRESS SUCH PROBLEMS: 140, 143, 166



## FOSSIL FUEL

COAL, OIL, OR NATURAL GAS PRODUCED BY NATURAL PROCESSES OVER MILLIONS OF YEARS: 10, 23, 46, 80–82, 136, 148–56

## FRACKING

A NEW METHOD OF EXTRACTING FOSSIL FUELS, SHORT FOR "HYDRAULIC FRACTURING": 46

## GLACIAL PERIOD

SCIENTIFIC NAME FOR WHAT IS COMMONLY CALLED AN **ICE AGE**: A PERIOD OF TIME WITH EXTENSIVE GLACIERS: 25–38

## GLOBAL WARMING

SEE **CLIMATE CHANGE**

## GREENHOUSE GAS

A GAS THAT DOESN'T INTERACT MUCH WITH RELATIVELY SHORT WAVELENGTH RADIATION (THE ULTRAVIOLET AND VISIBLE RADIATION INCOMING FROM THE SUN) BUT INTERACTS STRONGLY WITH RELATIVELY LONG WAVELENGTH RADIATION (THE INFRARED RADIATION OUTGOING FROM THE EARTH). THE PRINCIPAL GREENHOUSE GASES ON EARTH ARE WATER VAPOR, CARBON DIOXIDE (CO<sub>2</sub>), AND METHANE; LESS-IMPORTANT GREENHOUSE GASES INCLUDE NITROUS OXIDE, SF<sub>6</sub>, AND MANY OTHERS: 21, 58–62, 172–78



METHANE (CH<sub>4</sub>): 58, 124, 172, 176–77  
SULFUR HEXAFLUORIDE (SF<sub>6</sub>): 172, 178  
WATER VAPOR: 40, 58, 96



## ICE AGES

A PERIOD OF TIME WITH EXTENSIVE GLACIERS, FOR EXAMPLE FROM ABOUT 120,000 TO 12,000 YEARS AGO; SCIENTISTS SOMETIMES REFER TO THESE AS **GLACIAL PERIODS**: 25–38

## ICE-ALBEDO EFFECT

SEE **ALBEDO**

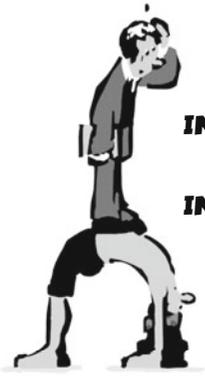
## ICE CORE

A VERTICAL "ROD" OF ICE, DRILLED FROM A GLACIER OR ICE SHEET, THAT CAN BE USED TO STUDY THE HISTORY OF THE EARTH'S CLIMATE BY EXAMINING THE CONTENTS OF DIFFERENT LAYERS THAT CORRESPOND TO DIFFERENT TIMES; FOR EXAMPLE, THE ANALYSIS OF AIR BUBBLES TRAPPED IN THE ICE CAN BE USED TO ESTIMATE CO<sub>2</sub> CONCENTRATIONS, AND THE PREVALENCE OF CERTAIN RARE MOLECULES (SUCH AS DEUTERIUM, A FORM OF H<sub>2</sub>O ALSO CALLED HEAVY WATER) CAN BE USED TO ESTIMATE THINGS LIKE TEMPERATURE AND THE RATIO OF WATER TO ICE ON THE PLANET: 29

TEMPERATURE AND CO<sub>2</sub> DATA: 48–50

## ICE SHEET

A LARGE GLACIER SUCH AS THE GREENLAND ICE SHEET OR THE WEST ANTARCTIC ICE SHEET: 28, 94, 117



## **INFRARED (IR)**

SEE **ELECTROMAGNETIC RADIATION**

## **INSURANCE**

A METHOD OF ADDRESSING LOW-PROBABILITY RISKS (FOR EXAMPLE THE RISK OF GETTING IN A CAR ACCIDENT) BY MAKING REGULAR PAYMENTS IN EXCHANGE FOR COVERAGE IN CASE OF DISASTER; SPENDING MONEY NOW TO REDUCE CARBON EMISSIONS CAN BE THOUGHT OF AS AN "INSURANCE POLICY" AGAINST THE RISK OF A CLIMATE CHANGE DISASTER: 130–32, 137

## **INTERGLACIAL PERIOD**

A RELATIVELY WARM PERIOD IN BETWEEN ICE AGES; THE CURRENT INTERGLACIAL PERIOD, CALLED THE HOLOCENE, STARTED ABOUT 12,000 YEARS AGO: 29, 36–38

## **IPCC**

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, AN INTERNATIONAL BODY THAT HAS STUDIED CLIMATE CHANGE SINCE 1988; THEIR FIFTH ASSESSMENT REPORT (AR5) CAME OUT IN 2014: 68, 71, 123–24

## **K**

## **KEELING CURVE**

MEASUREMENTS OF ATMOSPHERIC CO<sub>2</sub> CONCENTRATIONS, STARTED BY CHARLES DAVID KEELING IN 1958: 41–47



## **M**

## **METHANE (CH<sub>4</sub>)**

SEE **GREENHOUSE GAS**

## **MILANKOVITCH CYCLES**

VARIATIONS IN THE EARTH'S ORBIT AROUND THE SUN CAUSED BY GRAVITATIONAL INTERACTIONS WITH OTHER PLANETS; THESE VARIATIONS DON'T SIGNIFICANTLY CHANGE THE AMOUNT OF SOLAR RADIATION THAT REACHES THE EARTH OVER THE COURSE OF A YEAR, BUT THEY DO AFFECT TIMING, I. E., HOW MUCH RADIATION ARRIVES AT DIFFERENT TIMES OF THE YEAR: 30–32, 50

MILUTIN MILANKOVITCH (1879–1958) WAS A SERBIAN MATHEMATICIAN WHO ARGUED THAT THESE VARIATIONS CAUSED THE ICE AGES. OUR SIMPLIFIED VERSION OF HIS THEORY FOCUSES ON THE EFFECTS OF "STRONG SEASONS" AND "WEAK SEASONS," BUT HIS ACTUAL FOCUS WAS ON SUMMER IN THE NORTHERN HEMISPHERE (NOTABLY AT 65 DEGREES NORTH LATITUDE), WITH COLD SUMMERS IN THE NORTH LEADING TO GLACIAL ADVANCE AND WARM SUMMERS IN THE NORTH LEADING TO GLACIAL RETREAT.

## **MITIGATION**

EFFORTS TO REDUCE ATMOSPHERIC CONCENTRATIONS OF GREENHOUSE GASES; CONTRAST WITH **ADAPTATION**: 132, 184

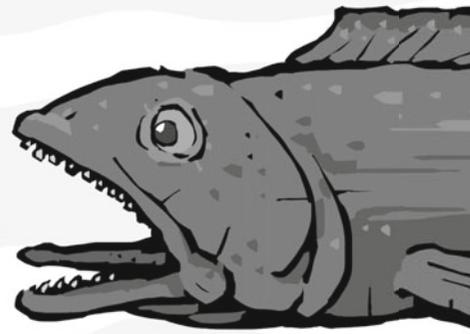
## **MONTREAL PROTOCOL**

A GLOBAL TREATY SIGNED IN 1987 TO PROTECT THE OZONE LAYER BY PHASING OUT OZONE-DEPLETING CHEMICALS SUCH AS CFCs: 21, 143



N

**NEGATIVE FEEDBACK LOOP**  
SEE **FEEDBACK**



O

**OCEAN ACIDIFICATION**

AN INCREASE IN THE CONCENTRATION OF HYDROGEN IONS IN THE OCEANS, SOMETIMES CALLED GLOBAL WARMING'S EQUALLY EVIL TWIN: 46–47, 98–100, 106, 147, 155



**OFFSETS**

THE IDEA THAT AN INDIVIDUAL, COMPANY, OR COUNTRY CAN PAY FOR CARBON REDUCTIONS ELSEWHERE (FOR EXAMPLE, BY PLANTING TREES) INSTEAD OF REDUCING THEIR OWN EMISSIONS: 179–82

**OZONE (O<sub>3</sub>)**

A MOLECULE CONSISTING OF THREE OXYGEN ATOMS; OZONE EXISTS BOTH AT GROUND LEVEL, WHERE IT IS A POLLUTANT RELATED TO SMOG, AND HIGH UP IN THE ATMOSPHERE, WHERE IT FORMS THE **OZONE LAYER** THAT BLOCKS HARMFUL UV RADIATION: 19–21



P

**PHENOLOGY**

THE STUDY OF THE TIMING OF BIRD MIGRATIONS, PLANT FLOWERING, AND OTHER LIFE CYCLE EVENTS IN PLANTS AND ANIMALS: 12, 73

**PHOTOSYNTHESIS**

A CHEMICAL REACTION THAT USES SUNLIGHT TO SUSTAIN LIFE, MOST COMMONLY **OXYGENIC PHOTOSYNTHESIS** THAT CONSUMES CARBON DIOXIDE AND PRODUCES OXYGEN AS A BYPRODUCT, THEREBY CONTRIBUTING TO THE CARBON CYCLE: 17–18, 42–43

**POPULATION**

THE NUMBER OF PEOPLE ON THE PLANET, EXPECTED TO RISE TO 10 OR 11 BILLION BY 2100 FROM 6 BILLION IN 2000 AND 1.6 BILLION IN 1900: 5, 81, 118, 190

AND "FIVE CHINAS": 80–81

**POSITIVE FEEDBACK LOOP**

SEE **FEEDBACK**

S

**SCIENTIFIC METHOD**

A PROCESS OF LEARNING AND DISCOVERY THAT INVOLVES DEVELOPING AND REFINING HYPOTHESES AND TESTING THOSE HYPOTHESES AGAINST REAL-WORLD DATA: 63–74, 124

**SEA LEVEL RISE**

ONE OF THE RISKS ASSOCIATED WITH CLIMATE CHANGE, RISING SEA LEVELS ARE RELATED TO BOTH THE THERMAL EXPANSION OF WARMING OCEANS AND THE MELTING OF LAND-BASED ICE: 92–94, 116–17, 124



## SMITH, ADAM

AUTHOR OF *THE WEALTH OF NATIONS*, ADAM SMITH (1723–1790) WAS A SCOTTISH PHILOSOPHER AND ECONOMIST WHO COINED THE “INVISIBLE HAND” METAPHOR: 4, 142



## SNOWBALL EARTH

A PLANET WITH TEMPERATURES COLD ENOUGH TO FREEZE SEAWATER, EVEN AT THE EQUATOR; SCIENTISTS DEBATE ABOUT WHETHER THE EARTH EVER GOT THIS COLD: 22, 24

## SUBSIDY

PAYMENTS TO THE PRODUCERS OF A PRODUCT; CONTRAST WITH TAXES, ESPECIALLY CARBON TAXES: 154

## SULFUR DIOXIDE (SO<sub>2</sub>)

A GAS THAT, AFTER BEING RELEASED INTO THE ATMOSPHERE, CAN FORM SULFUR PARTICLES THAT REFLECT SOLAR RADIATION; ALSO IMPORTANT IN ACID RAIN: 146–47, 178

T



## TAX SWAP

THE IDEA OF INCREASING TAXES ON “BADS” SUCH AS POLLUTION AND USING THE TAX REVENUE TO REDUCE TAXES ON “GOODS” SUCH AS INCOME: 163, 169



## TEMPERATURE

AVERAGING SURFACE TEMPERATURES AROUND THE PLANET OVER THE COURSE OF A YEAR YIELDS THE GLOBAL AVERAGE TEMPERATURE, CURRENTLY AROUND 15°C (59°F): 52, 124

## CAUTIONARY NOTE FOR AMERICANS:

THE FAHRENHEIT SCALE (°F) USED IN THE USA DIFFERS FROM THE CELSIUS SCALE (°C) COMMONLY USED IN SCIENCE, SO EXTREME CAUTION IS NEEDED. WATER FREEZES AT 0°C = 32°F AND BOILS AT 100°C = 212°F; THESE ARE BOTH EXAMPLES OF THE GENERAL FORMULA GOING FROM °C TO °F:

$$x^{\circ}\text{C} = (1.8x + 32)^{\circ}\text{F}$$

FOR EXAMPLE, 20°C = (36 + 32) = 68°F.

A RELATED (BUT SIMPLER) FORMULA MUST BE USED FOR **TEMPERATURE CHANGES**. FOR EXAMPLE, AN INCREASE (OR DECREASE) OF 5°C IS EQUAL TO AN INCREASE (OR DECREASE) OF 9°F, WHICH IS AN EXAMPLE OF THE GENERAL FORMULA FOR INCREASES OR DECREASES:

$$+x^{\circ}\text{C} = +1.8x^{\circ}\text{F}$$

FOR EXAMPLE, +4°C = +7.2°F.

NOTE THAT A ROUGH APPROXIMATION IS THAT A CHANGE OF x°C EQUALS A CHANGE OF 2x°F. ALSO NOTE THAT YOU CAN REVERSE THESE FORMULAS TO GO FROM °F TO °C:

$$x^{\circ}\text{F} = (x - 32) / (1.8)^{\circ}\text{C} \quad \text{AND} \quad +x^{\circ}\text{F} = +x / (1.8)^{\circ}\text{C}$$





### **TRAGEDY OF THE COMMONS**

SITUATIONS SUCH AS TRAFFIC CONGESTION, OVERFISHING, AND POLLUTION IN WHICH INDIVIDUAL SELF-INTEREST DOES NOT LEAD TO A GOOD OUTCOME FOR THE GROUP AS A WHOLE; ECONOMISTS EMPHASIZE THAT THESE SITUATIONS FEATURE COMMON PROPERTY, WHICH CAN BE MISUSED BY SELF-INTERESTED INDIVIDUALS: 135–44, 148, 160, 187, 191



U

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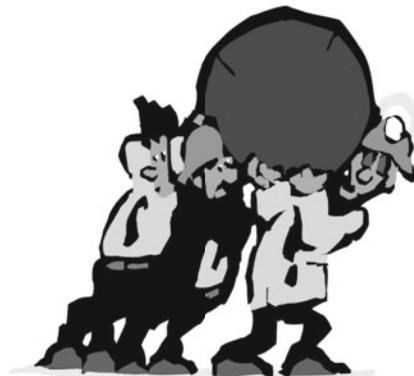
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